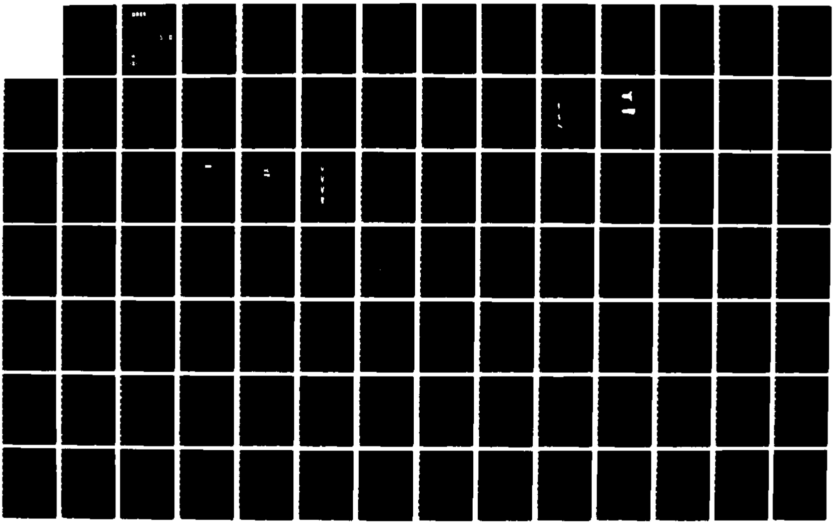
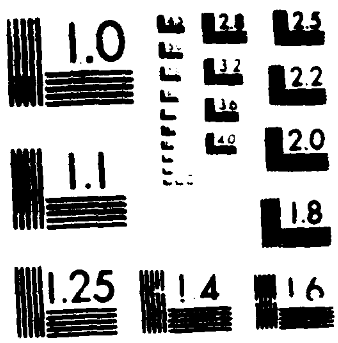
AD-A179 857 SFFSTAB A COMPUTER PROGRAM TO CALCULATE THE AERODYNAMIC 1/2
STABILITY OF A SE (U) DEFENCE RESEARCH ESTABLISHMENT
SUFFIELD RALSTON (ALBERTA) C A WEICKERT MAR 87
UNCLASSIFIED DRES-SM-1194 F/G 19/10 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

National Defence / Défense nationale

UNCLASSIFIED

AD-A179 857

DTIC FILE COPY

UNLIMITED
DISTRIBUTION

DRES

SUFFIELD MEMORANDUM

NO. 1194

SFFSTAB:

A COMPUTER PROGRAM TO CALCULATE THE AERODYNAMIC STABILITY OF A SELF-FORGING FRAGMENT (U)

DTIC
ELECTE
MAY 0 4 1987
S D
D

by

C.A. Weickert

Project No. 231SB

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

March 1987

DEFENCE RESEARCH ESTABLISHMENT SUFFIELD, RALSTON, ALBERTA

DEFENSIO PER SCIENTIAM

Canada

87 4 30 109

UNCLASSIFIED

DEFENCE RESEARCH ESTABLISHMENT SUFFIELD
RALSTON, ALBERTA

SUFFIELD MEMORANDUM NO. 1194

SFFSTAB: A COMPUTER PROGRAM TO CALCULATE THE AERODYNAMIC STABILITY OF A SELF-FORGING FRAGMENT

by

C.A. Weickert

UNCLASSIFIED

DEFENCE RESEARCH ESTABLISHMENT SUFFIELD
RALSTON, ALBERTA

SUFFIELD MEMORANDUM NO. 1194

SFFSTAB: A COMPUTER PROGRAM TO CALCULATE THE AERODYNAMIC STABILITY OF A SELF-FORGING FRAGMENT

by

C.A. Weickert

ABSTRACT

An aerodynamic stability computer program (SFFSTAB) has been developed for calculating the spin rate required for stabilization of a self-forging fragment. An aerodynamic stability criterion which combined gyroscopic and dynamic stability was used together with a technique for calculating aerodynamic coefficients. SFFSTAB is a useful tool for conducting aerodynamic stability parameter studies for different fragment shapes. Complete documentation of the computer program including sample problem, flowchart and FORTRAN listing is provided. (Keywords: explosions, fragments, computer program

(1)

TABLE OF CONTENTS

LIST OF FIGURES

NOMENCLATURE

Symbol	Description
A	axial force
C_D	drag coefficient
CG	center of mass
C_m	pitching-moment coefficient
$C_{m_{p\alpha}}$	derivative of the magnus-moment coefficient
$(C_{m_q} + C_{m_{\dot{\alpha}}})$	pitch-damping coefficient
C_{m_α}	$\frac{dC_m}{d\alpha}$; derivative of pitching-moment coefficient
C_N	normal-force coefficient
C_{N_α}	derivative of the normal-force coefficient
C_p	pressure coefficient
CP	center of pressure

.../vi

NOMENCLATURE (cont'd)

d	projectile diameter
d_b	base diameter of projectile
d_n	base diameter of segment
D	drag force
I_x	axial moment of inertia
I_y	transverse moment of inertia
K_x	dimensionless axial radius of gyration
K_y	dimensionless transverse radius of gyration
l	projectile length
L	lift force or distance from the Magnus center of pressure to the center of gravity
ℓ	length of segment
M	Mach number
m	mass
N	normal force

.../vii

NOMENCLATURE (cont'd)

P	projectile spin rate
R	resultant force
R_1	Reynolds Number based on 1
S	projectile cross-sectional area
S_d	dynamic stability factor
S_g	gyroscopic stability factor
V	velocity
α	angle of attack
θ	angle between surface tangent and free stream or flare angle
ρ	density

DEFENCE RESEARCH ESTABLISHMENT SUFFIELD
RALSTON, ALBERTA

SUFFIELD MEMORANDUM NO. 1194

SFFSTAB: A COMPUTER PROGRAM TO CALCULATE THE AERODYNAMIC STABILITY OF A SELF-FORGING FRAGMENT

by

C.A. Weickert

1.0 INTRODUCTION

The purpose of this report is to describe the criteria for stability and to document a program which is capable of calculating aerodynamic coefficients and spin rates required for stabilization of self-forging fragments.

The Demolitions Group at the Defence Research Establishment Suffield (DRES) is responsible for military related research in Canada on demolitions and demolition devices. DRES is developing a Self-Forging Fragment (SFF) technology base suitable for the study of the application of SFF devices to demolition problems.

One of the projects currently under study is the application of spin stabilization to self-forging fragments. The project requires both numerical and experimental capabilities to study the SFF formation and flight stability.

The DRES Flash X-ray Facility has the capability of obtaining formation, shape, stability characteristics and trajectory data for the fragments. The fragments can be monitored over a 60 m flight path by using a combination of X-ray radiographs and yaw screens. To fulfill the numerical requirements, and the requirement for a code to determine what parameters to vary, a computer program was developed to calculate the aerodynamic coefficients for a self-forging fragment and to predict its stability.

Section 2 describes self-forging devices and the fragment characteristics, including selected results from experimental tests. In Section 3 aerodynamic stability criteria are presented. Section 4 describes the computer program Self-Forging Fragment STABility (SFFSTAB). The results for sample problems are also described in this section.

The DATCOM [3] method for obtaining aerodynamic coefficients is documented in Appendix A, and properties of spherical segments and truncated cones are given in Appendix B. A flowchart and a FORTRAN listing of the computer program with input and output for the sample problem presented in Section 4 are contained in Appendix C.

2.0 SELF-FORGING FRAGMENT DEVICE

A typical self-forging fragment (SFF) device, as illustrated in Figure 1, consists of a body which is filled with high explosive (HE) and a metal liner. The charge is initiated by a detonator and an explosive booster. Upon initiation, the resulting detonation wave travels through the HE subjecting the metal liner to high forces causing a single fragment to be formed, and accelerating this fragment to a high velocity. Typical SFF's have initial velocities of

2-3 km/sec. These fragments can travel to distances well in excess of 1000 calibers, beyond which accuracy becomes a problem.

In many self-forging fragment designs, the objective is to produce a long rod-type fragment as opposed to a ball-type fragment since the former has, in general, greater target penetration capability. However, a long fragment is inherently unstable in flight as illustrated in Figure 2. This figure shows flash radiographs of the fragment as it deviates from the intended flight path. This instability results in a loss of accuracy and a lower target penetration capability. Current SFF designs use a flared tail fragment. This feature increases the stability of the fragment and improves its accuracy. However, the flared tail increases the aerodynamic drag on the fragment, resulting in a shorter flight path, and it also reduces the penetrating capability of the fragment since the tail does not contribute to the penetration process. If a fragment could be spin stabilized, the requirement for a flared tail would be eliminated (see Figure 3). This would result in increased performance of the self-forging fragment device. The main aim of this report is to present a computer program for calculating the requirements for aerodynamic stability and to illustrate its application to self-forging fragments with flared rod and blunt cone shapes.

3.0 AERODYNAMICS OF SELF-FORGING FRAGMENTS

Determination of the aerodynamic stability of a projectile requires a knowledge of the mass distribution within the projectile (i.e., location of the center of gravity, moments of inertia) and the aerodynamic parameters (i.e., lift, drag, etc.). For most projectiles the mass distribution can be calculated or measured from the projectile design and the aerodynamic parameters can be determined by wind tunnel

experiments. However, for self-forging fragments the actual shape of the fragment that will be formed from a liner is unknown, so that these properties cannot be determined a priori. Flash X-radiography can be used to determine the outer profile of the fragment but in general, unless very high-energy X-rays are used, the radiographs do not reveal any information about the interior of the fragment. Also, the high velocities of self-forging fragments requires that very specialized hypersonic tunnels be used to measure the aerodynamic parameters. Numerical techniques are therefore used to calculate the self-forging fragment stability. This report describes the SFFSTAB code developed for this purpose. After a review of the aerodynamic forces and moments acting on a projectile, formulas for gyroscopic and dynamic stability used in a stability criterion derived by Murphy [2] are presented. Aerodynamic coefficients required for the stability formulas are provided by the DATCOM method [3]. Results for typical fragment shapes are also presented.

The aerodynamic forces acting on a projectile are illustrated in Figures 4 and 5. The resultant (R) of the forces acting on a projectile can be decomposed into the drag force (D) and lift force (L) in the wind coordinate system, or the normal force (N) and axial force (A) in the body coordinate system. The resultant force (R) acts on the center of pressure (CP) which is the point at which the net moment is zero. An additional force which acts on a projectile is the magnus force (see Figure 5). The combination of the air flowing over the projectile and the spin of the projectile results in an asymmetric boundary layer thickness distribution. This effectively changes the aerodynamic shape of the body which results in a force normal to the angle of attack plane.

The location of the center of pressure (CP) depends on the velocity of the projectile. Therefore, it is more convenient to use

the center of gravity (CG) or center of mass which depends only on the mass distribution in the projectile. The forces acting at the center of pressure are replaced by an equivalent force and moment combination at the center of gravity. The aerodynamic forces and moments are usually non-dimensionalized. The corresponding force and moment coefficients, C_{FORCE} and C_{MOMENT}, take the general forms:

$$C_{FORCE} = FORCE \;/\; \tfrac{1}{2}\rho V^2 S, \tag{3.1}$$

$$C_{MOMENT} = MOMENT \;/\; \tfrac{1}{2}\rho V^2 S l, \tag{3.2}$$

where ρ and V are the air density and velocity respectively, S is the projectile cross-sectional area, and l is the projectile length.

The dominant aerodynamic effect is the pitching-moment or static-moment coefficient (C_m). This coefficient represents the overturning or pitching moment which is a function of the distance between the centers of mass (CG) and pressure (CP). If the derivative of the pitching moment (C_{m_α}) with respect to the angle of attack (α) is negative, the CP is located behind the CG and the projectile is said to be statically stable (i.e., stable as long as it is not perturbed). Conversely, if C_{m_α} is greater than zero, then the CP is located ahead of the CG and the projectile is statically unstable. Physically, the center of gravity is the pivot point of the projectile. The resultant force (R) acts at the center of pressure in a direction towards the rear of the projectile. Thus, if the force acts ahead of the pivot point the projectile is statically unstable, and conversely if it acts behind the pivot point the projectile is statically stable.

Stabilization of projectiles is accomplished by two techniques, fin and spin stabilization. Fin stabilization is accomplished by

adding fins (or a flared tail in the case of a self-forging fragment) to the projectile in order to shift the center of pressure behind the center of gravity. In the second technique, the projectile is spun in order to maintain the center of pressure as close as possible to the trajectory which is the path of the center of mass. For a spinning projectile a gyroscopic stability factor (S_g) is defined by Murphy [2] as:

$$S_g = \frac{2}{\pi\rho} \frac{I_x^2}{I_y} \left(\frac{P}{V} \right)^2 \frac{1}{C_{m_\alpha}} \frac{1}{d^3}, \qquad (3.3)$$

where P and V are the projectile spin rate and velocity, ρ is the air density, d is the projectile diameter, C_{m_α} is the derivative of the pitching-moment coefficient, and I_x and I_y are the axial and transverse moments of inertia, respectively. The dominant aerodynamic coefficient affecting the motion of a spinning projectile is the pitching-moment coefficient. In order for a statically unstable projectile to have a periodic motion (i.e., continue to spin) and not tumble, the gyroscopic stability factor (S_g) must be greater than one. Physically the motion in this case is the same as that of a spinning top. Gyroscopic stability, like static stability (i.e., center of pressure behind the center of gravity) is required for stable oscillatory motion, but this alone does not ensure that small perturbations acting on the projectile will not grow and result in unstable motion. In order to characterize the response to small perturbations, a dynamic stability factor (S_d) was derived by Murphy [2] from the equations of motion of a spinning projectile. This stability factor is:

$$S_d = \frac{2\,(C_{N_\alpha} - C_D) + 2\,K_x^{-2}\,C_{m_{p\alpha}}}{C_{N_\alpha} - 2C_D - K_y^{-2}\,(C_{mq} + C_{m_{\dot\alpha}})}, \tag{3.4}$$

where K_x and K_y are the dimensionless axial and transverse radii of gyration, respectively, the sum $(C_{mq} + C_{m_{\dot\alpha}})$ is the pitch-damping coefficient, C_{N_α} and $C_{m_{p\alpha}}$ are the derivatives of the normal-force and magnus-moment coefficients, respectively, and C_D is the drag coefficient.

The relation between the spin rate of a projectile and various types of projectile stability was characterized by Murphy [2]. His results are summarized on the stability diagram shown in Figure 6. The boundary between dynamic stability and instability is given by the equation:

$$\frac{1}{S_g} = S_d\,(2 - S_d). \tag{3.5}$$

This equation can be used in conjunction with equation (3.3) to determine the stability bounds on the projectile spin rate (P). The following conclusions can be made by referring to Figure 6:

(1) A dynamically stable projectile must be gyroscopically stable (i.e., $\frac{1}{S_g} < 1$);

(2) If S_d lies in the interval (0-2), a statically unstable projectile can be stabilized by spinning it at a sufficiently high rate and a statically stable projectile is always dynamically stable;

(3) If S_d lies outside this interval, a statically unstable projectile cannot be spin-stabilized. In fact, a statically stable projectile can be made dynamically unstable by spin.

It should be pointed out that the results shown in Figure 6 assume that S_d does not depend on the spin rate. If there is a strong dependence of the magnus moment on spin then the method of determining stability must be modified [2].

The effects of the various coefficients in equation (3.4) on the dynamic stability factor (S_d) have been studied by Platou [5]. He presents a series of graphs that can be used as a guide to determine the influence of projectile design changes on the dynamic stability.

In order to apply the stability criterion described above, the mass distribution (moments of inertia, radii of gyration) and the aerodynamic coefficients in equations (3.3) and (3.4) must be known. As previously mentioned, determination of the aerodynamic coefficients for self-forging fragments by experimental wind tunnel testing is difficult and therefore numerical techniques are used for this purpose. A compendium of methods (DATCOM) for determining aerodynamic coefficients for subsonic to hypersonic velocity regimes has been assembled by the US Air Force [3]. For the case of hypersonic velocities (applicable to self-forging fragments), Newtonian impact theory is used to determine the pressure coefficient for any surface element. Fluid particles that impact the surface are assumed to lose their normal component of momentum, whereas the tangential component is preserved. The impact results in a pressure coefficient (C_p) of the form

$$C_p = 2 \sin^2 \delta \qquad (3.6)$$

where δ is the angle between a tangent to the surface and the direction of the free stream of fluid particles. This pressure coefficient is then used to derive analytical expressions for the aerodynamic coefficients for a particular shape of projectile. The DATCOM method uses design charts and empirical relationships to determine the aerodynamic coefficients at hypersonic velocities for projectile shapes composed of one or more cone frustums with or without a spherical nose. As will be shown later these shapes can be used for self-forging fragments.

The method will now be illustrated for the derivative of the normal-force coefficient (C_{N_α}) which is given by

$$\frac{dC_N}{d\alpha} = C_{N_\alpha} = \sum_{n=1}^{m} \left(C_{N_\alpha}\right)_n \left(\frac{d_n}{d_b}\right)^2 \tag{3.7}$$

where d_n and d_b are the base diameters of the segment and projectile, respectively. To apply this equation, the body is divided into m segments, the first segment being either a spherical nose or a cone frustum, and each succeeding segment being a cone frustum. The parameter C_{N_α} for a spherical nose, based on its base area, is obtained from Figure 7, and C_{N_α} for a cone frustum, based on the base area of the specific segment, is obtained from Figure 8. The ratio $(d_n/d_b)^2$ refers C_{N_α} to the base area of the configuration. By evaluating C_{N_α} for each segment and then applying equation (3.7) the derivative of the normal-force coefficient (C_{N_α}) for the complete projectile is obtained. The method applied to the remainder of the aerodynamic coefficients (except for the derivative of the magnus moment coefficient ($C_{m_{p\alpha}}$)) is given in Appendix A. The derivative of the magnus moment coefficient ($C_{m_{p\alpha}}$) can be determined from the following empirical equation [5]:

$$C_{m_{p\alpha}} = \frac{26.3\ (l/d)^2 L}{\sqrt{R_l}} \tag{3.8}$$

where l and d are the projectile length and diameter, respectively, L is the distance from the magnus center of pressure to the center of gravity and R_l is the Reynolds Number based on l.

All of the information previously described in this section can be incorporated into a computer program for calculating aerodynamic stability of self-forging fragments.

4.0 SFFSTAB: AERODYNAMIC STABILITY PROGRAM

A computer program SFFSTAB has been developed for calculating the aerodynamic stability of a self-forging fragment. In this program, physical properties such as volume, mass, and moments of inertia are first calculated. Formulas for these properties for hollow spherical segments and hollow truncated cones have been derived and are given in Appendix B. Next, the aerodynamic coefficients are computed using the DATCOM method (Appendix A). Gyroscopic and dynamic stability are calculated and the projectile's stability characteristics are determined from the stability criteria illustrated in Figure 6. If the fragment is dynamically unstable, but can be spin stabilized, then a minimum fragment spin rate for stabilization is calculated. Since the fragment is initially formed from a saucer-shaped liner, it is necessary to translate the fragment spin rate into a spin rate for the initial device configuration. This is simply done by dividing the liner into segments and applying conservation of angular momentum (see Figure 9).

As an example of the application of the SFFSTAB computer program consider the self-forging fragment radiograph shown in Figure 10.

As illustrated a five segment model was used to represent the fragment. The objective of the calculation was to determine the stability characteristics of this fragment and to determine if it could be spin stabilized. The actual output from the SFFSTAB program is given as the sample problem in Appendix C. For the solid fragment shape shown in Figure 10, the calculated minimum spin rate for stabilization was 66280 RPM. Based on conservation of angular momentum this corresponds to an initial SFF charge spin rate of 3860 RPM.

SFFSTAB is a useful tool for conducting parametric studies for different fragment shapes. The dependence of stability on the exterior shape is illustrated in Figure 11, where the fragment spin rate required for dynamic stability as a function of the flare angle θ is shown for typical fragment shapes. The interior profile also has a significant effect on the dynamic stability. Some typical results obtained for fragments with similar exterior profiles but varying degrees of hollowness are shown in Figure 12. Notice that as the fragment shape is changed from hollow to completely solid the spin rate required for dynamic stability increases.

5.0 SUMMARY

In summary, an aerodynamic stability criterion which combined gyroscopic and dynamic stability has been presented. A technique for calculating the aerodynamic coefficients was used together with the stability criterion for calculating the stability of self-forging fragments. A computer program (SFFSTAB) was developed using this information and sample problems illustrating the effects of parameters such as interior and exterior fragment profiles have been presented. This report provides the complete documentation required to use the program SFFSTAB.

REFERENCES

1. Hermann, J.W., Jr., Randers-Pehrson, G. and Berus, E.R., "Experimental and Analytical Investigation of Self-Forging Fragments for the Defeat of Armor at Extremely Long Standoff" (U), Third International Symposium on Ballistics, Karlsruhe, Germany, 1977.

2. Murphy, C.H., "Free Flight Motion of Symmetric Missiles" (U), Report No. 1216, Ballistic Research Laboratories, Maryland, July 1963.

3. Hoak, D.E., "USAF Stability and Control DATCOM" (U), April 1978.

4. "Elements of Armament Engineering, Part 2, Ballistics" (U), Army Materiel Command Engineering Design Handbook Series, AMCP 706-107, September 1963.

5. Platou, A.S., "The Influence of the Magnus Moment on the Dynamic Stability of a Projectile" (U), Memorandum Report No. 2155, Ballistic Research Laboratories, Maryland, January 1972.

6. Fisher, L.R., "Equations and Charts for Determining the Hypersonic Stability Derivatives of Combinations of Cone Frustums Computed by Newtonian Impact Theory" (U). NASA TN D-149, November 1959.

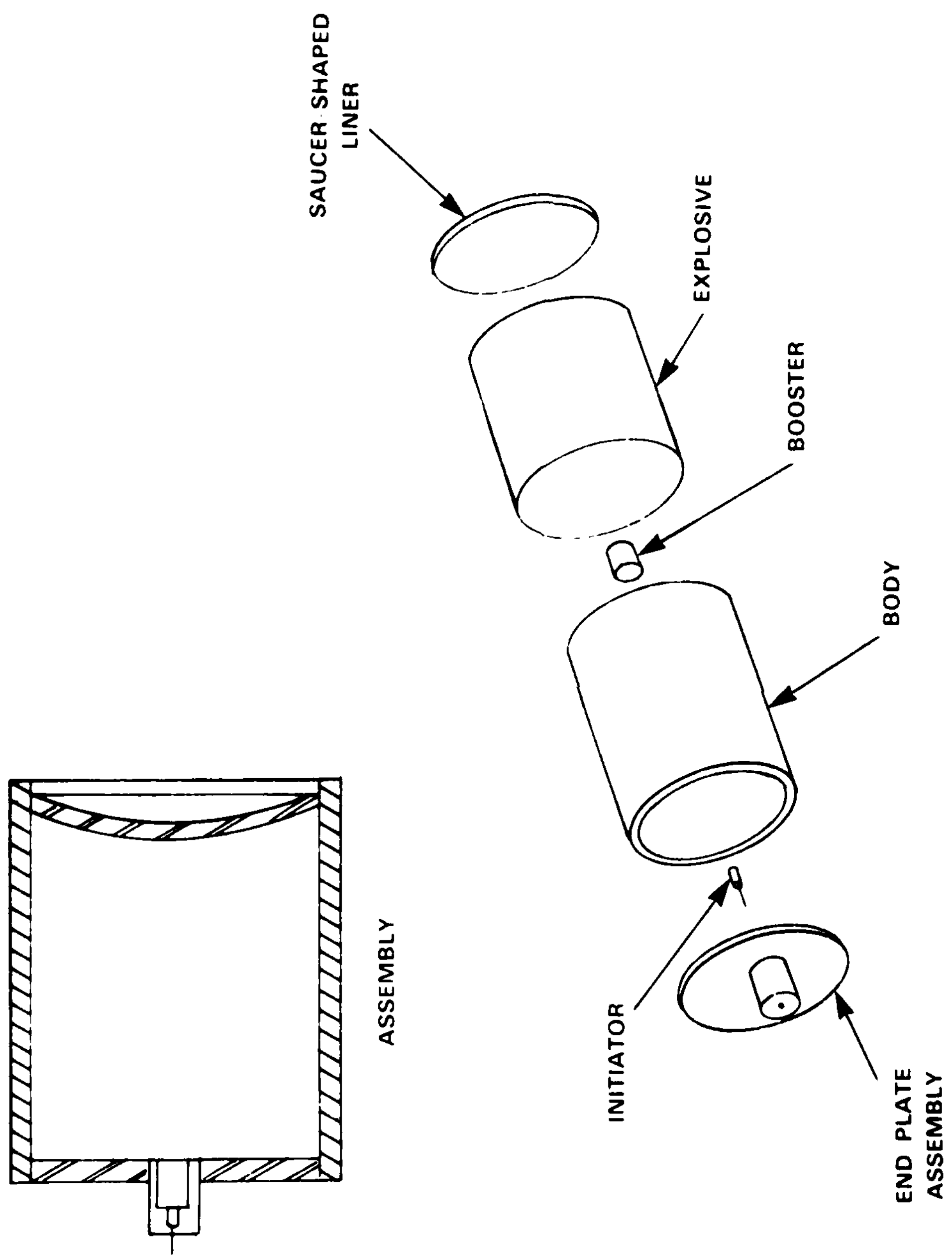


Figure 1

SELF-FORGING FRAGMENT DEVICE

Reference [1]

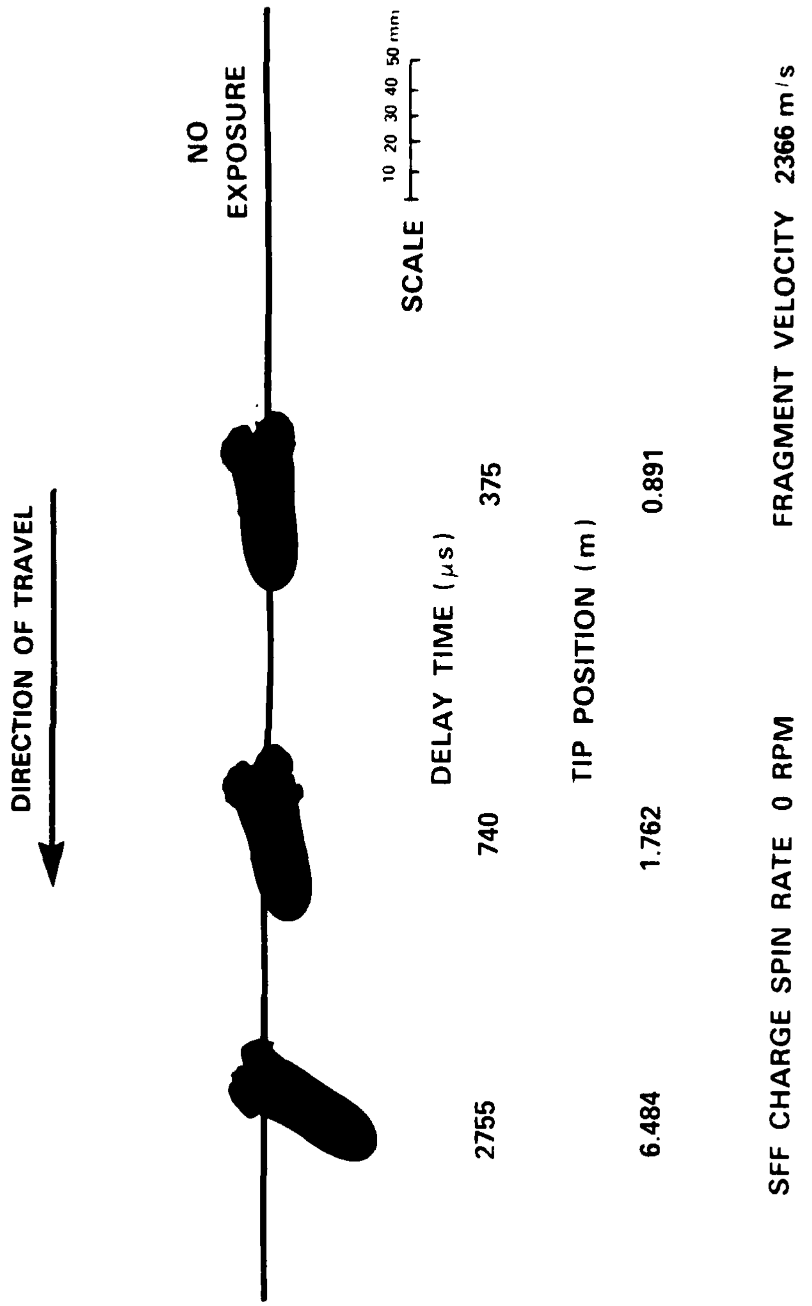


Figure 2

RADIOGRAPHS OF UNSTABLE FRAGMENT

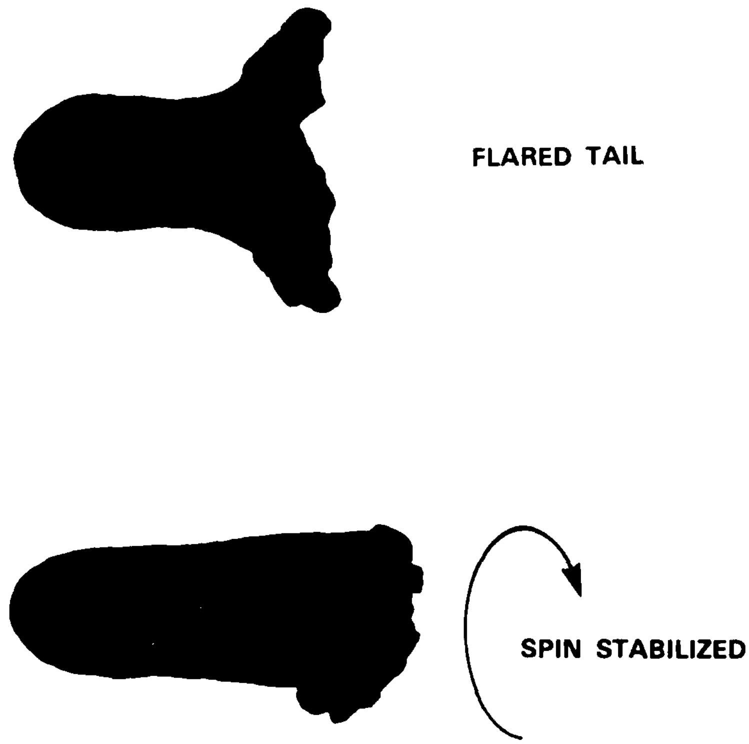
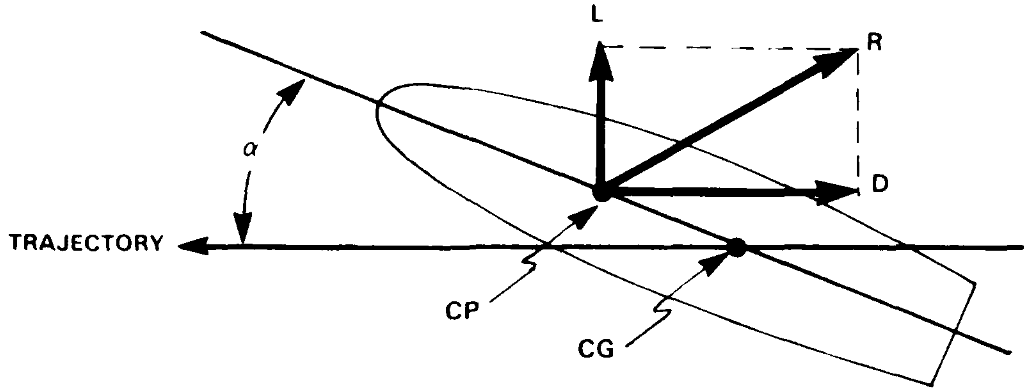
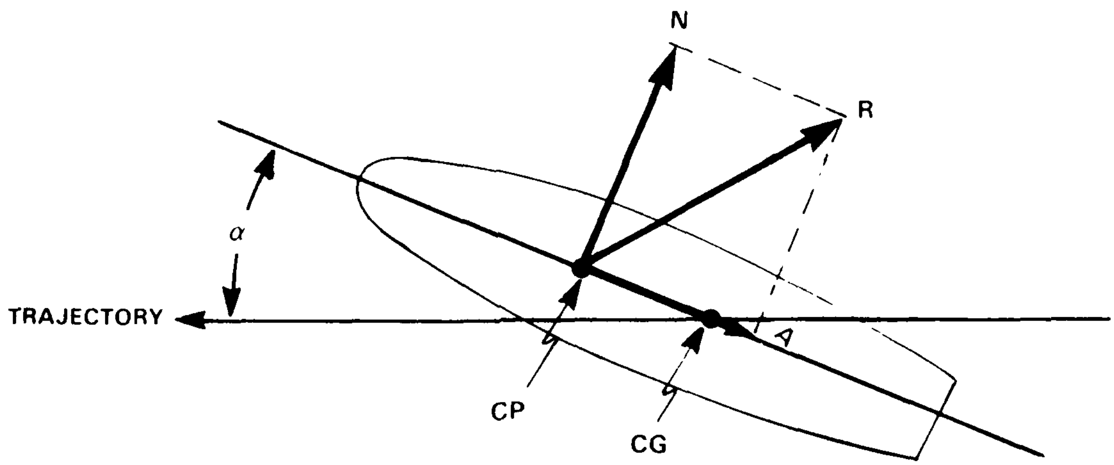


Figure 3

TECHNIQUES FOR SELF-FORGING FRAGMENT STABILIZATION



a) WIND COORDINATES



b) BODY COORDINATES

L	LIFT FORCE	A	AXIAL FORCE
D	DRAG FORCE	α	ANGLE OF ATTACK
R	RESULTANT FORCE	CP	CENTER OF PRESSURE
N	NORMAL FORCE	CG	CENTER OF GRAVITY

Figure 4

AERODYNAMIC FORCES ON A BODY

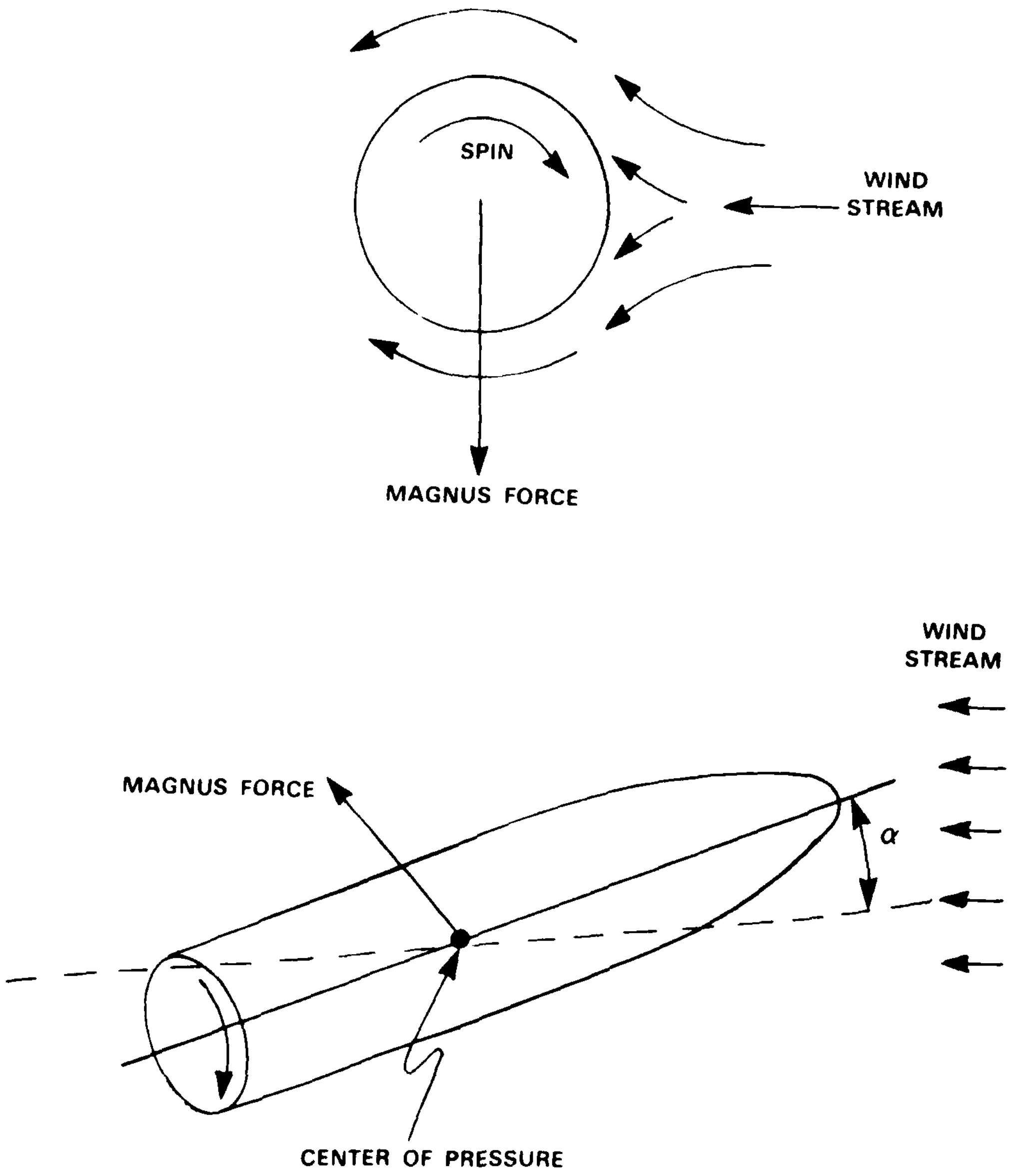


Figure 5

MAGNUS FORCE (Reference [4])

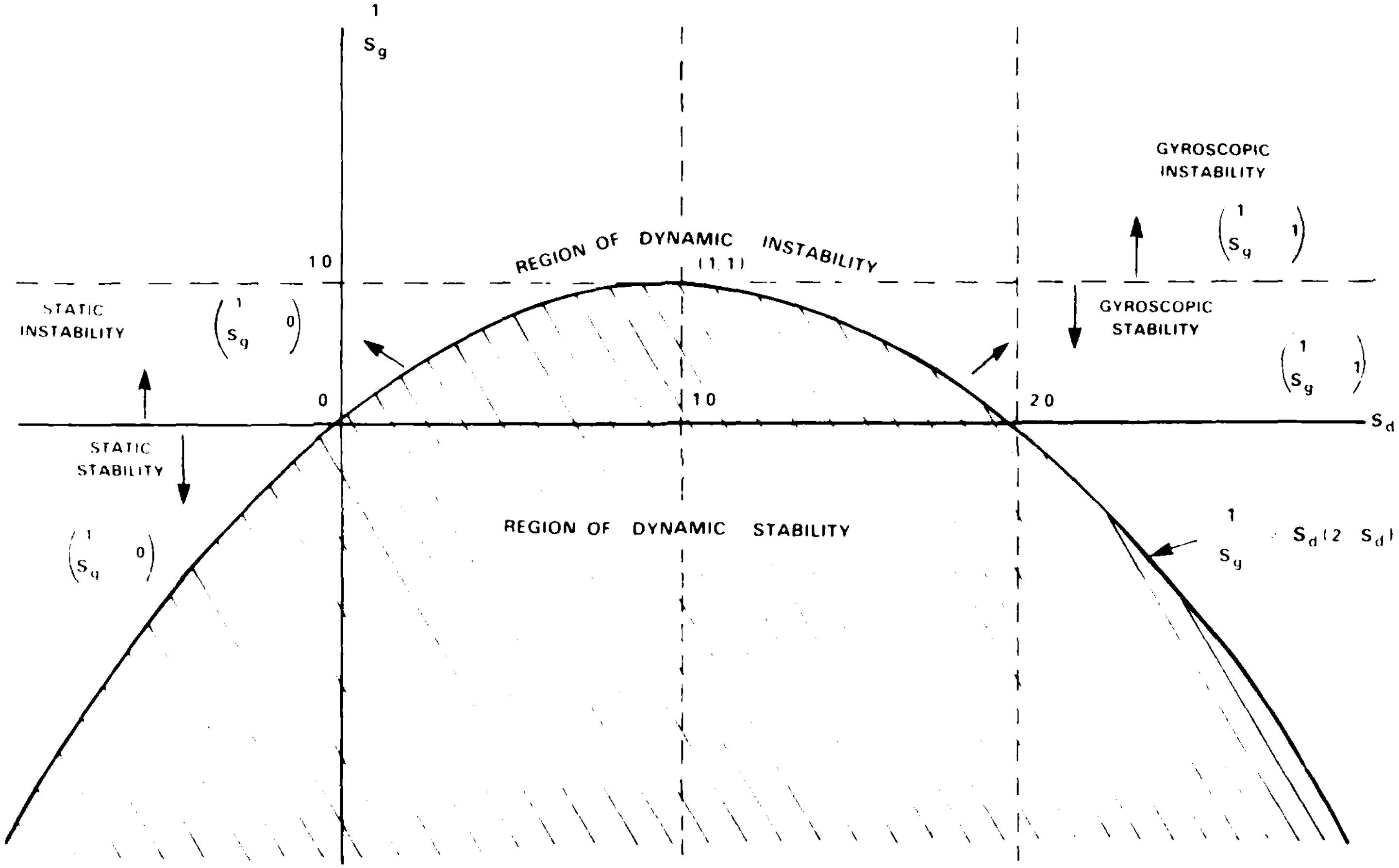


Figure 6

STABILITY DIAGRAM $\frac{1}{S_g}$ *VS* S_d, WHERE S_g = GYROSCOPIC STABILITY AND S_d = DYNAMIC STABILITY (Reference [2])

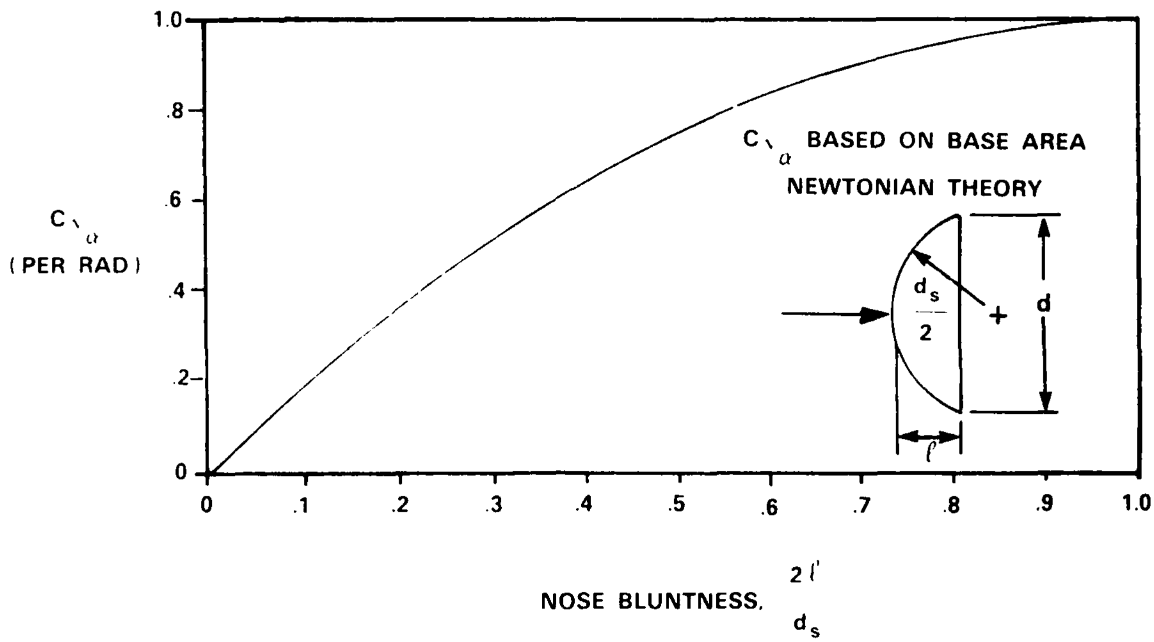


Figure 7

DERIVATIVE OF THE NORMAL FORCE COEFFICIENT FOR SPHERICAL SEGMENTS (Reference [3])

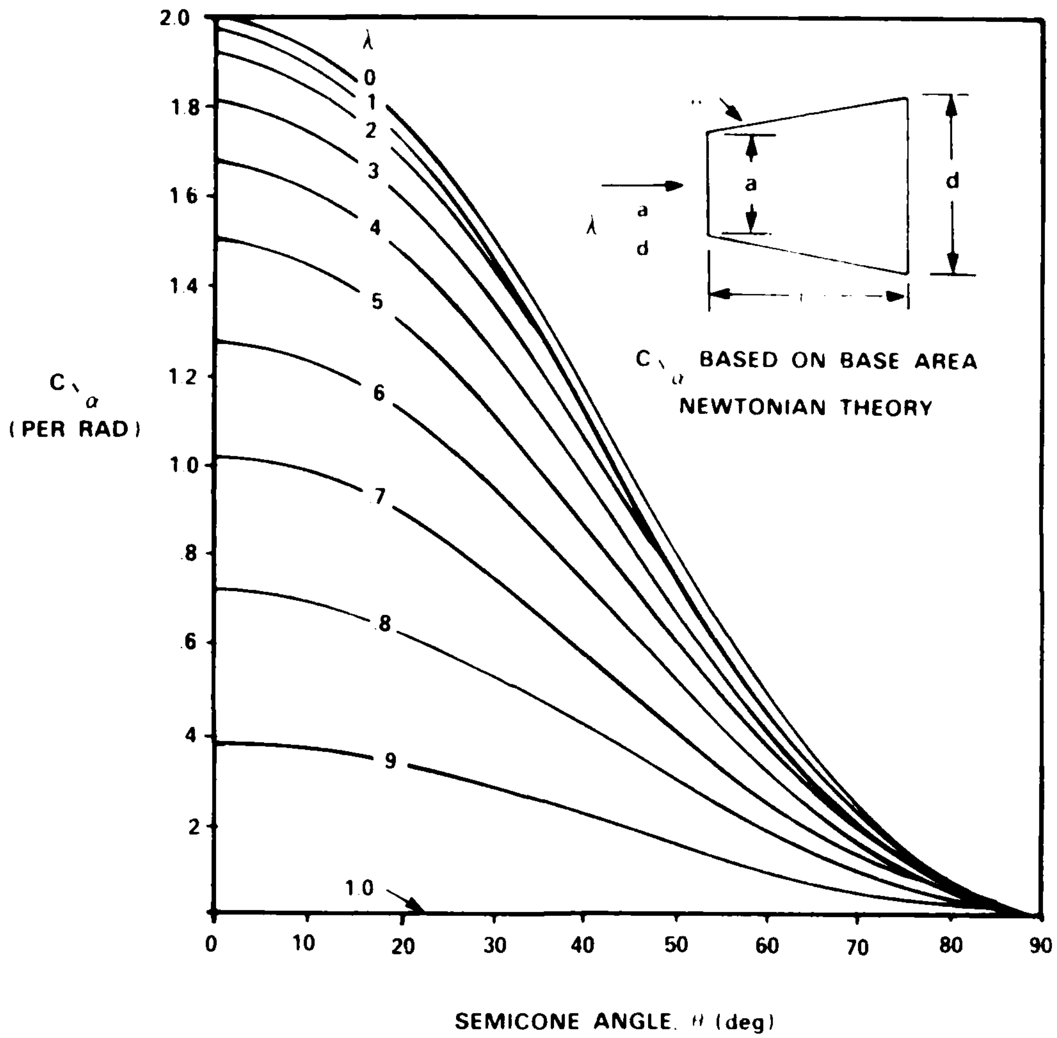


Figure 8

DERIVATIVE OF THE NORMAL FORCE COEFFICIENT FOR CONE FRUSTUMS
(Reference [3])

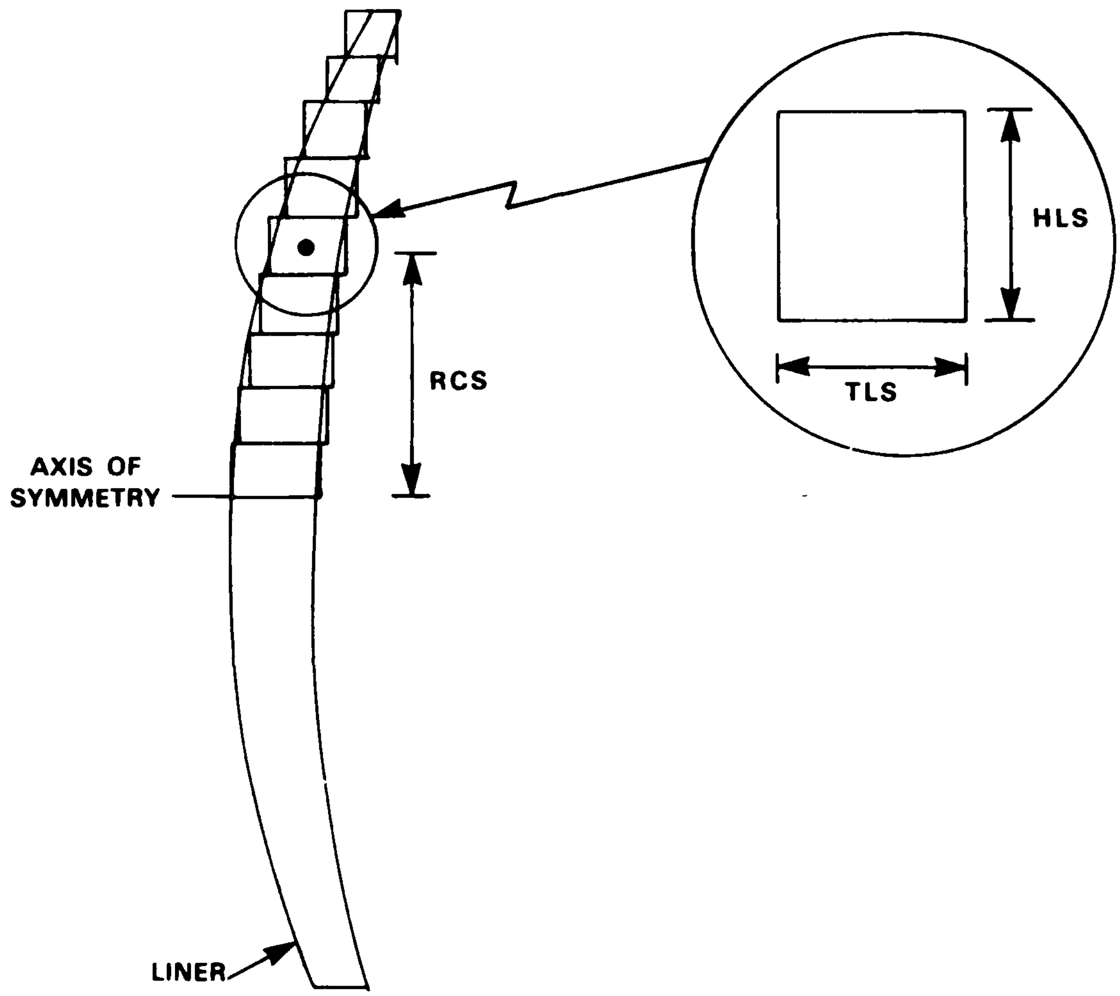
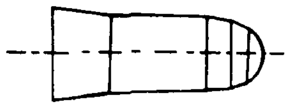


Figure 9

APPROXIMATION OF LINER GEOMETRY BY SEGMENTS

EXPERIMENT 01
RADIOGRAPH



AERODYNAMIC
MODEL FOR
SFFSTAB

REQUIRED FRAGMENT SPIN RATE = 6940 (RAD/SEC) = 66280 (RPM)
REQUIRED CHARGE (SFF) SPIN RATE = 404 (RAD/SEC) = 3860 (RPM)

Figure 10

"SFFSTAB" RESULTS FOR EXPERIMENTALLY OBSERVED FRAGMENT

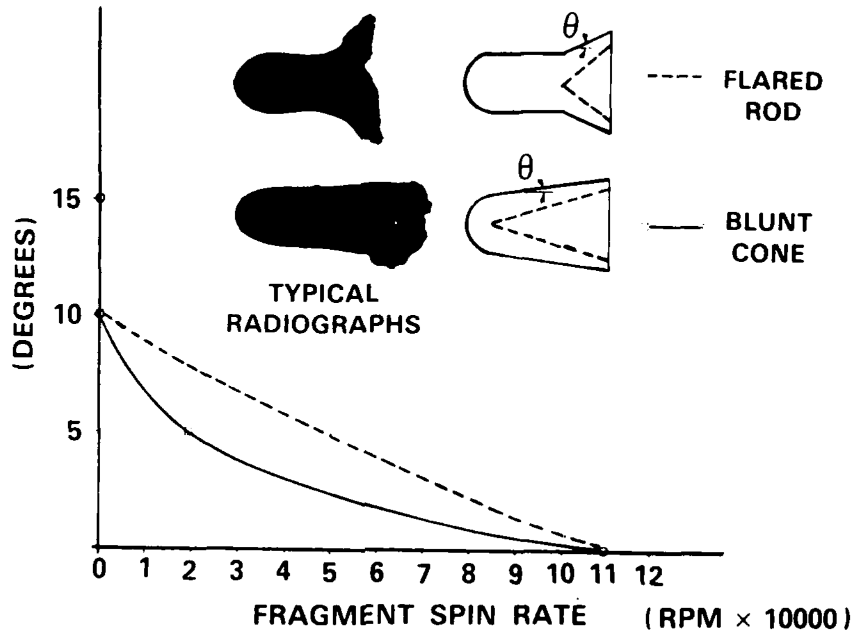


Figure 11

FRAGMENT SPIN RATE REQUIRED FOR DYNAMIC STABILITY *VS* FLARE ANGLE θ

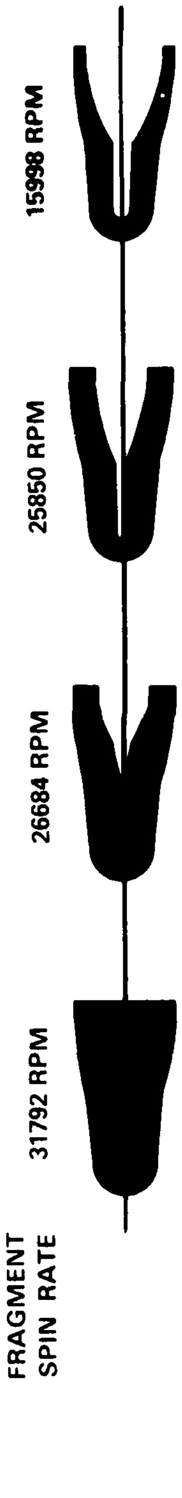


Figure 12

SPIN RATE REQUIRED FOR DYNAMIC STABILITY OF
FRAGMENTS WITH DIFFERENT INTERIOR PROFILES

APPENDIX A - DATCOM METHOD

DATCOM METHOD FOR HYPERSONIC FLOW

The DATCOM Method [3] uses the results of Newtonian impact theory. Design charts and equations are presented in Reference 3, for determining the aerodynamic characteristics at hypersonic speeds of projectile shapes composed of one or more cone frustums with or without a spherical nose. The coefficients required for gyroscopic and dynamic stability equations are given in this Appendix. The relevant coefficients are:

i) C_{N_α} : NORMAL-FORCE-CURVE SLOPE

ii) C_{m_α} : PITCHING MOMENT CURVE SLOPE

iii) C_D : DRAG COEFFICIENT

iv) C_{N_q} : PITCHING DERIVATIVE

v) C_{m_q} : PITCHING DERIVATIVE

vi) $C_{m_{\dot{\alpha}}}$: BODY ACCELERATION DERIVATIVE

The information contained in this Appendix has been extracted from Reference 3.

i) C_{N_α}: NORMAL-FORCE-CURVE SLOPE

The normal-force-curve slope of a body composed of one or more cone frustums with or without a spherical nose, based on the body base area, is given by

$$\frac{dC_N}{d\alpha} = C_{N_\alpha} = \sum_{n=1}^{m} (C_{N_\alpha})_n \left(\frac{d_n}{d_b}\right)^2 \qquad (A.1)$$

To apply this equation the body is divided into m segments, the first segment being either a spherical nose or a cone frustum, and each succeeding segment a cone frustum. The normal-force-curve slope of a spherical nose, based on area, is obtained from Figure A-1. The normal-force-curve slope of a cone frustum, based on the base area of the specific segment, is obtained from Figure A-2. (Note that a cylinder is considered a cone frustum with $\Theta = 0$ and $a/d = 1.0$, and that $C_{N_\alpha} = 0$ by Newtonian impact theory.) *The ratio* $(d_n/d_b)^2$ *refers* the normal-force-curve slope to the base area of the configuration.

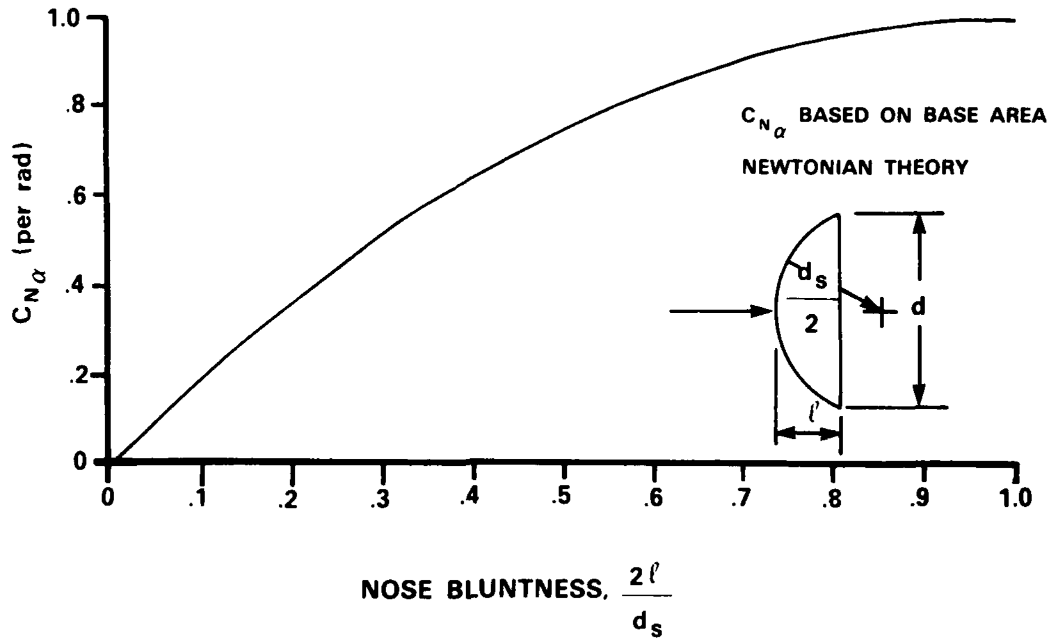


Figure A-1

NORMAL-FORCE-CURVE SLOPE FOR SPHERICAL SEGMENTS

(Reproduced from Figure 4.2.1.1-23 of Reference [3])

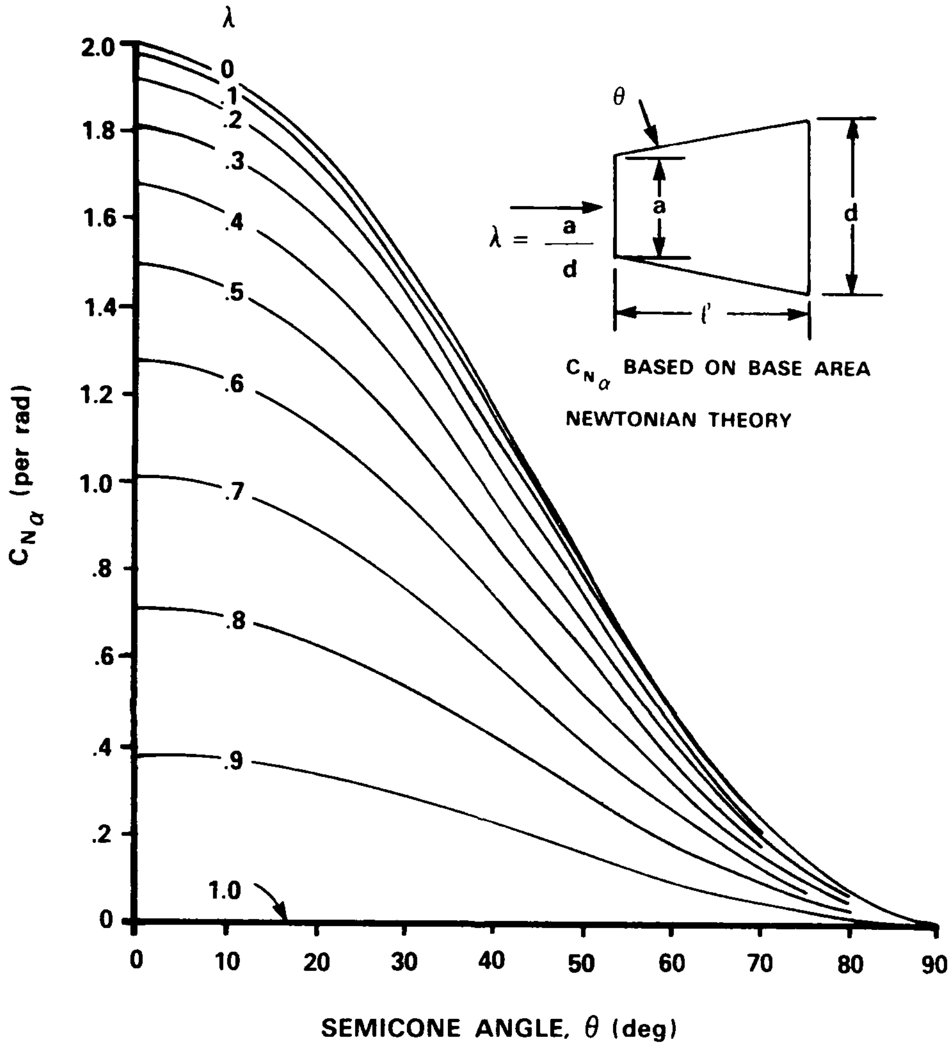


Figure A-2

NORMAL-FORCE-CURVE SLOPE FOR CONE FRUSTUMS

(Reproduced from Figure 4.2.1.1-26 of Reference [3])

ii) C_{M_α} : PITCHING MOMENT CURVE SLOPE

The procedure for computing the total pitching-moment-curve slope for a complex body is given in the following steps. The moment values for each individual segment of a multiple cone-frustum body with or without a spherical nose are referred to a moment axis at the front face of that particular segment, and are based on the product of the base area and base diameter of that particular segment.

Step 1: Compute C'_{m_α} for each body segment about its own front face, using Figures A-3 and A-4.

Step 2: Transfer the individual moment slopes to a common reference axis by applying the following moment transfer equation to each body segment.

$$C_{m_\alpha} = C'_{m_\alpha} + \frac{n}{d} C_{N_\alpha} \text{ (per radian)} \qquad \text{(A.2)}$$

where

C_{N_α} is the normal-force-curve slope of the individual cone-frustum or spherical nose segment, based on its own base area, from Figures A-2 and A-1, respectively.

d is the base diameter of the individual cone-frustum or spherical nose segment.

n is the distance from the front face of a given segment to the desired moment reference axis of the configuration, positive aft.

C'_{m_α} is the pitching-moment-curve slope of an individual segment from Figure A-3 for cone frustums and from Figure A-4 for spherical nose segments. C'_{m_α} is based on the product of the base area and the base diameter of the individual segment.

C_{m_α} is the pitching-moment-curve slope of an individual segment based on the product of the base area and base diameter of the individual segment and referred to a common reference axis.

Step 3: The transferred pitching-moment-curve slopes of the individual body segments are then converted to a common basis by

$$C_{m_\alpha} = \sum_{n=1}^{m} (C_{m_\alpha})_n \left(\frac{d_n}{d_b}\right)^3 \text{ (per radian)} \qquad \text{(A.3)}$$

where the subscript n refers to an individual segment of m segments, and C_{m_α} is referred to a common reference axis and is based on the product of the area and diameter of the base of the configuration $S_b d_b$.

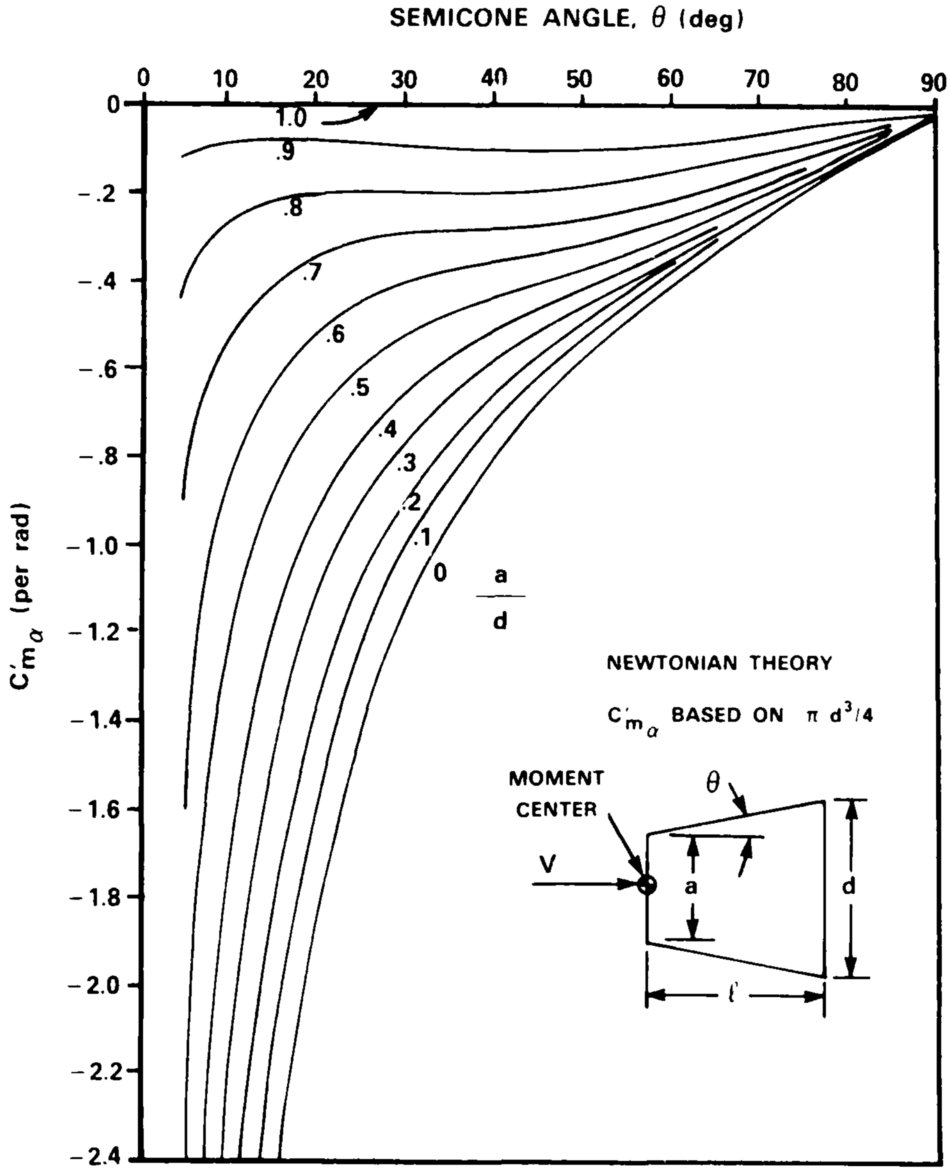


Figure A-3

C'_{m_α} FOR CONE FRUSTUMS

(Reproduced from Figure 4.2.2.1-25a of Reference [3])

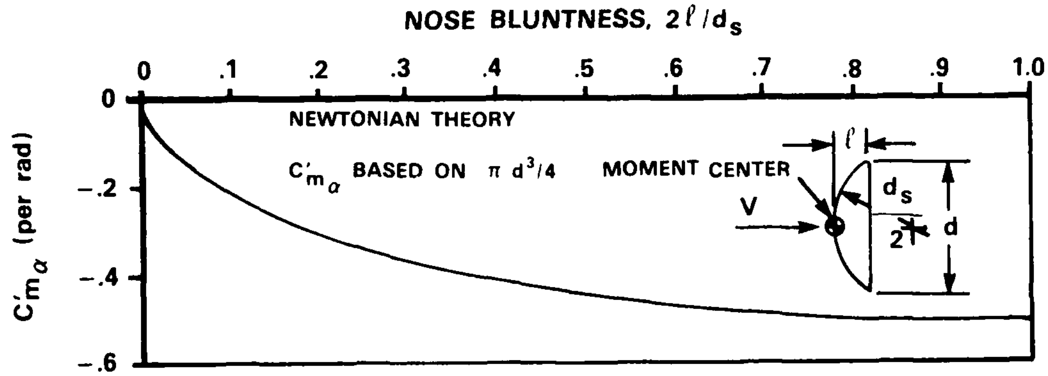


Figure A-4

C'_{m_α} FOR SPHERICAL SEGMENTS

(Reproduced from Figure 4.2.2.1-25b of Reference [3])

iii) C_D: DRAG COEFFICIENT

The zero-lift drag (based on the maximum frontal area) of a body composed of one or more cone frustums with or without a spherical nose is estimated by adding the pressure-drag coefficient of each segment to the body skin-friction drag coefficient.

$$C_{D_o} = C_{D_f} + \sum_{n=1}^{m} C_{D_{Pn}} \left(\frac{d_n}{d_{max}} \right)^2 \qquad (A.4)$$

The procedure to be followed in evaluating this equation is as follows:

Step 1: Divide the body into m segments, the first segment being either a spherical nose or a cone frustum, and each succeeding segment a cone frustum. The pressure-drag coefficient for a spherical nose or cone frustrum is obtained from Figures A-5 and A-6, respectively. The pressure-drag coefficients for the remainder of the segments are obtained from Figure A-7. The pressure-drag coefficients are based on the base area of the specific segment. The ratio $(d_n/d_{max})^2$ refers the pressure-drag coefficients to the maximum body frontal area.

Step 2: Obtain the body skin-friction drag coefficient by

$$C_{D_f} = 1.02\, C_{f_{inc}} \frac{C_{f_c}}{C_f} \frac{S_S}{S_B} \qquad (A.5)$$

where

$C_{f_{inc}}$ is the incompressible (M = 0) turbulent, flat-plate skin-friction coefficient, including roughness effects, as a function of Reynolds number based on the total length of the body ℓ_B. This value is obtained from Figure A-8.

ℓ is the reference length in inches.

k is the surface-roughness height in inches; it depends upon surface finish. Representative values for this parameter can be obtained from Table A-1.

The ratio ℓ/k is computed and Figure A-9 is used to obtain the cutoff Reynolds number. If the cutoff Reynolds number is greater than the computed Reynolds number for the specific configuration, the value of C_f is obtained from Figure A-8 at the computed Reynolds number. If the cutoff Reynolds number is less than the computed Reynolds number, the value of C_f is obtained from Figure A-8 at the cutoff Reynolds number.

$\frac{C_{f_c}}{C_f}$ is the ratio of compressible to incompressible skin-friction coefficient obtained from Figure A-10.

$\frac{S_S}{S_B}$ is the ratio of the body wetted area to maximum body frontal area.

If this method is applied at Mach numbers low enough so that the base drag is significant, the base drag should be added to the results obtained. Unfortunately, the only base-drag coefficient results available which are compatible with the Newtonian-theory results (restricted to bodies with forward facing slopes or cylinders, in which case the Newtonian results are equal to zero) are those for cylindrical afterbodies. The pressure-drag coefficient for cylindrical afterbodies is presented in Figure A-11 for $M < 10$.

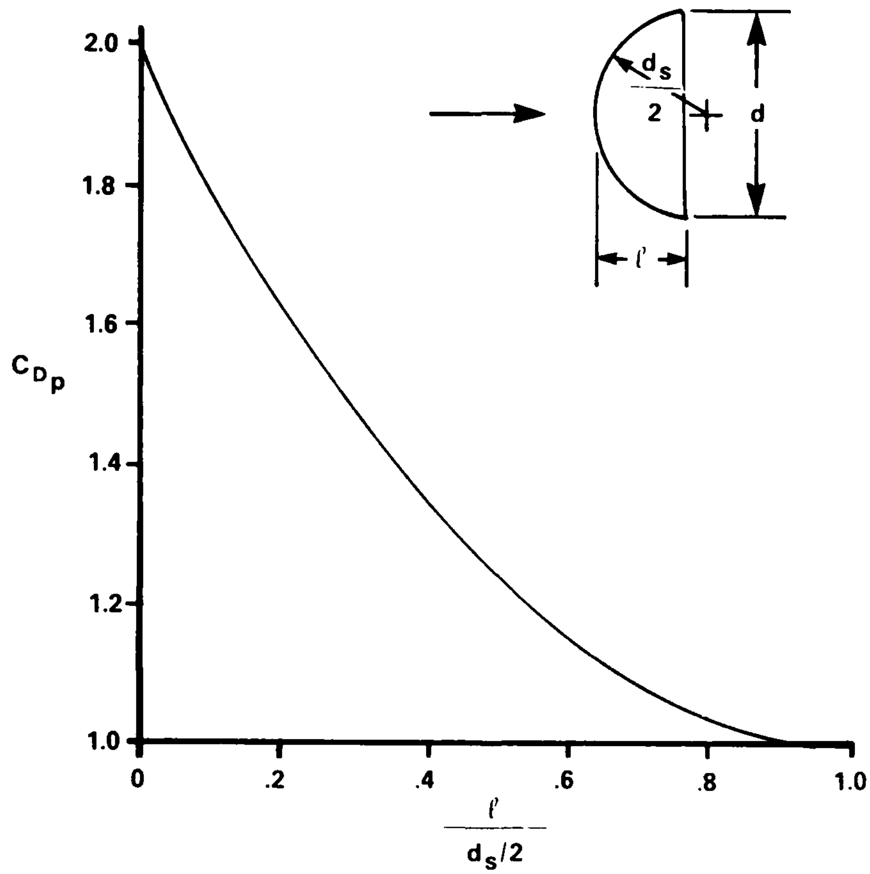


Figure A-5

NEWTONIAN DRAG COEFFICIENT FOR SPHERICAL SEGMENTS REFERRED TO BASE AREA OF SEGMENT

(Reproduced from Figure 4.2.3.1-66 of Reference [3])

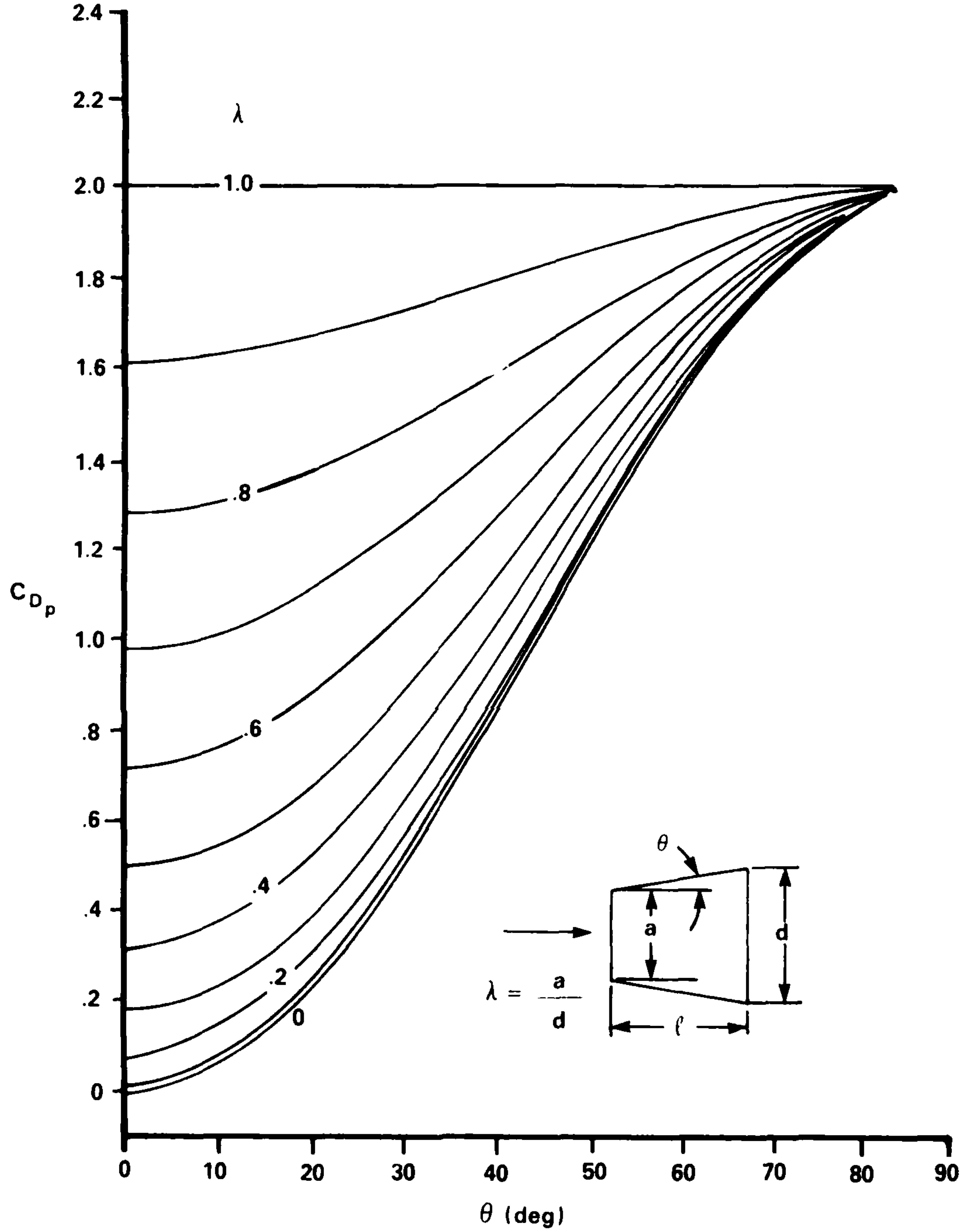


Figure A-6

DRAG COEFFICIENT FOR A CONE FRUSTUM CALCULATED FROM NEWTONIAN THEORY. THE GEOMETRIC PARAMETERS ARE RELATED BY THE EQUATION $\tan\theta = \dfrac{1-\lambda}{2(\ell/d)}$

(Reproduced from Figure 3 of Reference [6])

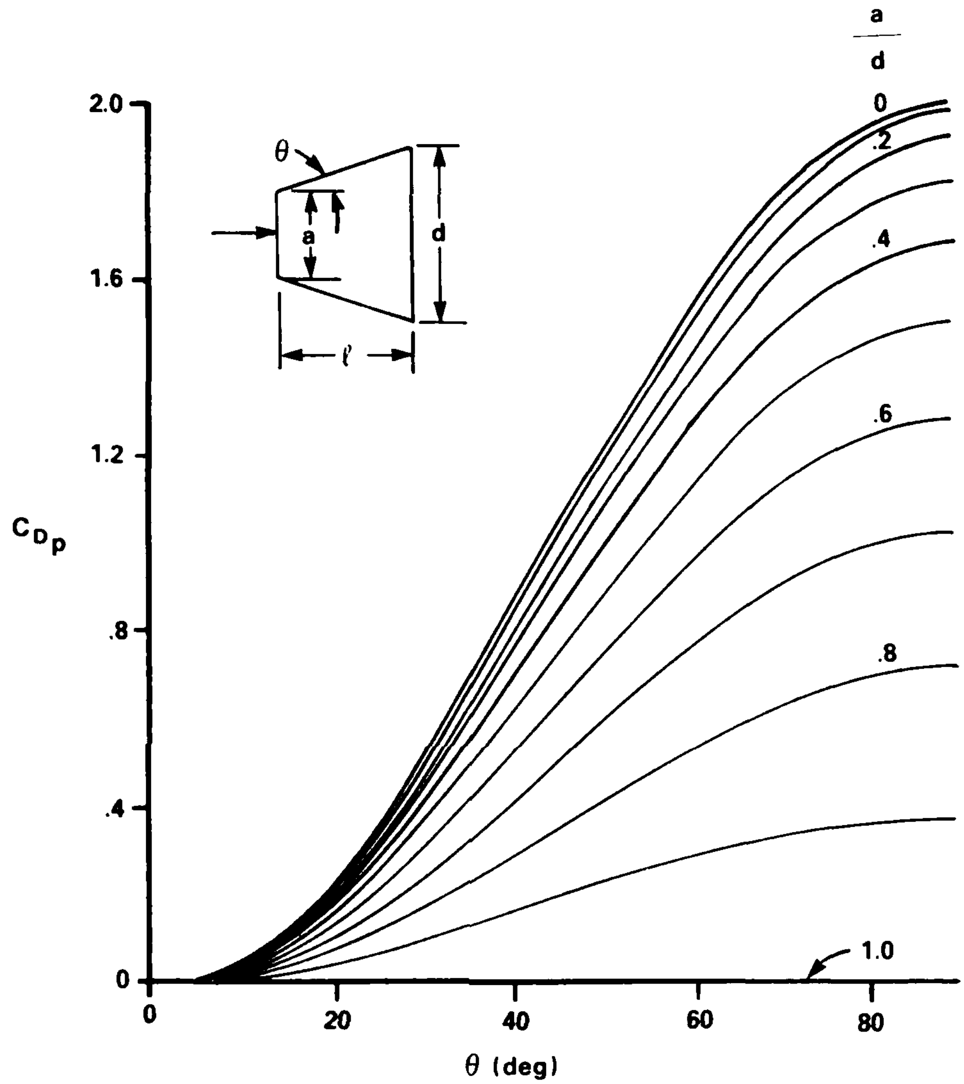


Figure A-7

DRAG-FORCE COEFFICIENT DUE ONLY TO THE INCLINED SIDES OF A CONE FRUSTUM CALCULATED BY NEWTONIAN THEORY. C_D IS BASED ON BODY BASE AREA S_b.

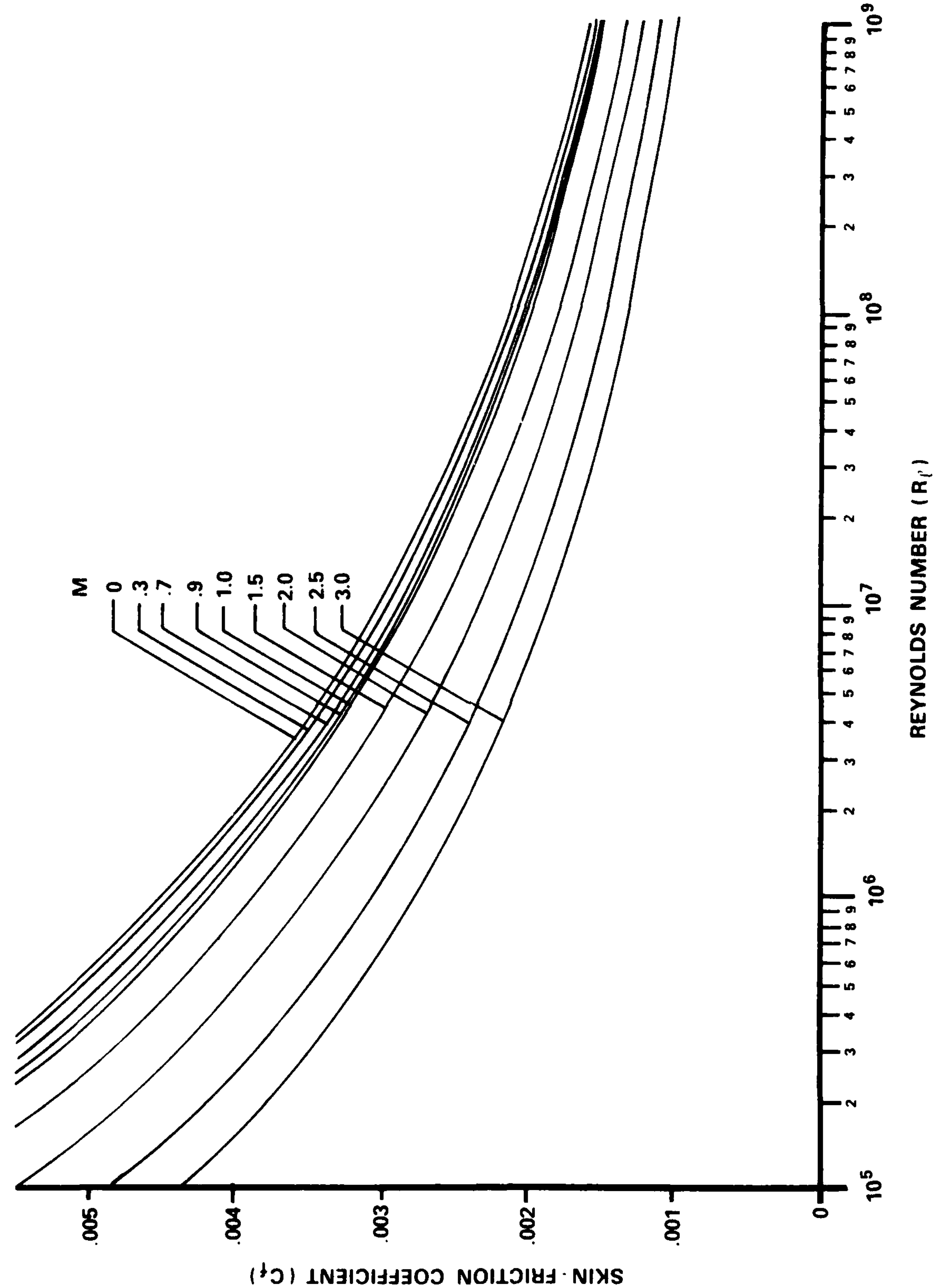


Figure A-8

TURBULENT MEAN SKIN-FRICTION COEFFICIENT ON AN INSULATED FLAT PLATE

(Reproduced from Figure 4.1.5.1-26 of Reference [3])

Table A-1

REPRESENTATIVE VALUES OF SURFACE-ROUGHNESS HEIGHT

(Reproduced from Table 4.1.5.1-A of Reference [3])

TYPE OF SURFACE	EQUIVALENT SAND ROUGHNESS k (inches)
Aerodynamically Smooth	0
Polished Metal or Wood	$0.02 - 0.08 \times 10^{-3}$
Natural Sheet Metal	0.16×10^{-3}
Smooth Matte Paint, Carefully Applied	0.25×10^{-3}
Standard Camouflage Paint, Average Application	0.40×10^{-3}
Camouflage Paint, Mass-Production Spray	1.20×10^{-3}
Dip-Galvanized Metal Surfaces	6×10^{-3}
Natural Surface of Cast Iron	10×10^{-3}

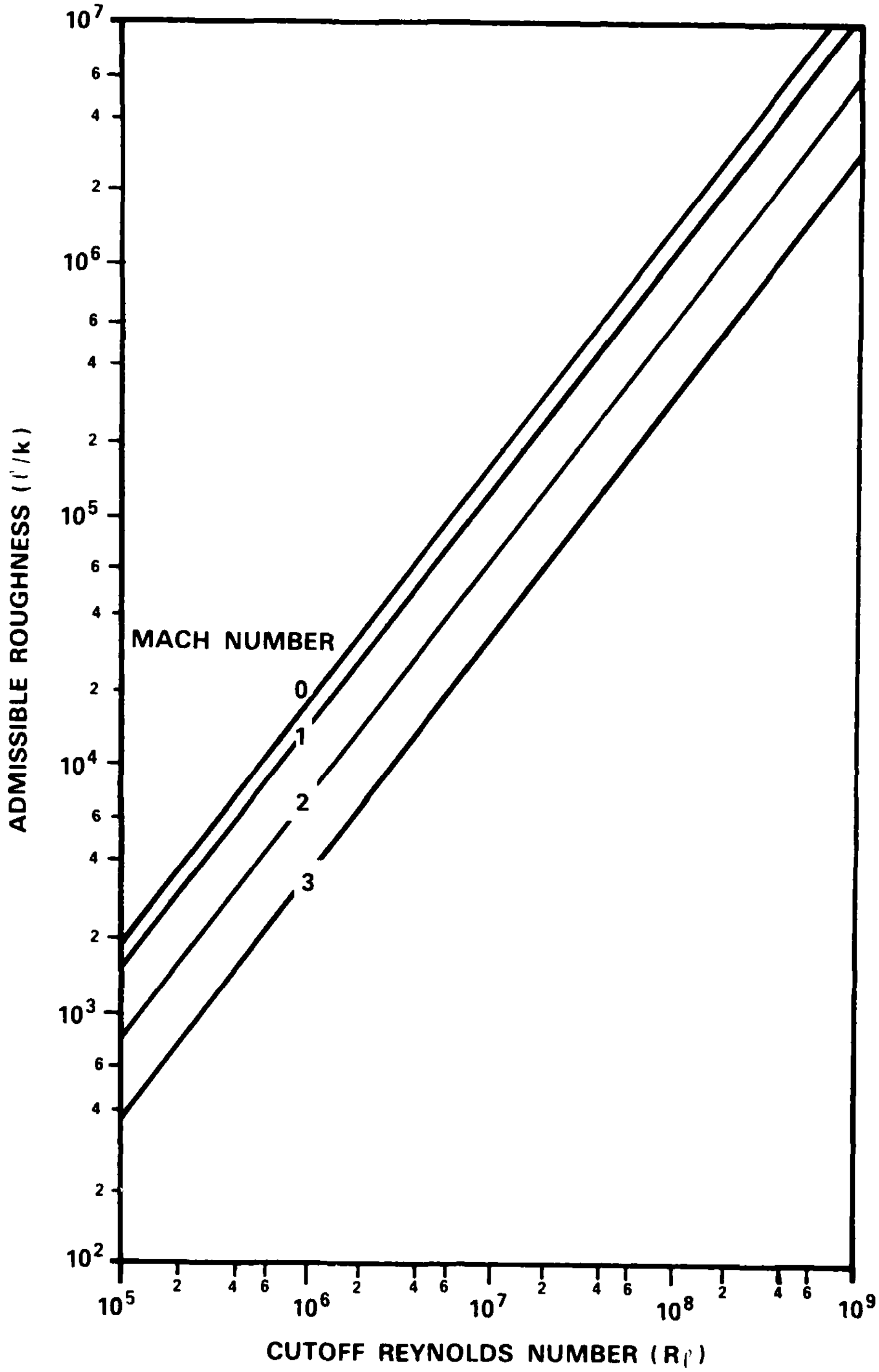


Figure A-9

CUTOFF REYNOLDS NUMBER

(Reproduced from Figure 4.1.5.1-27 of Reference [3])

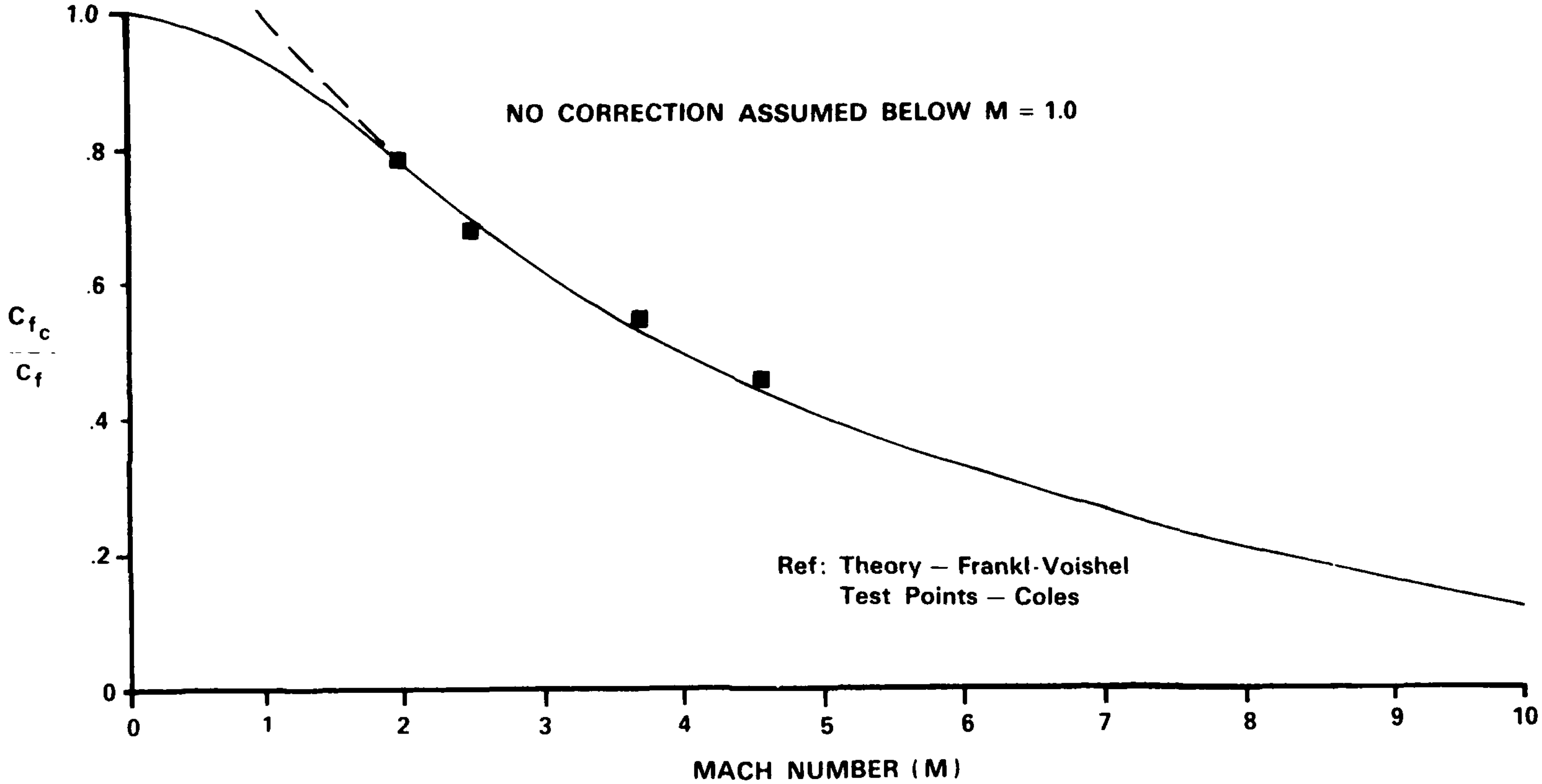


Figure A-10

COMPRESSIBILITY EFFECT ON TURBULENT SKIN FRICTION

(ZERO HEAT TRANSFER)

(Adapted from Figure 4.2.3.1-68 of Reference [3])

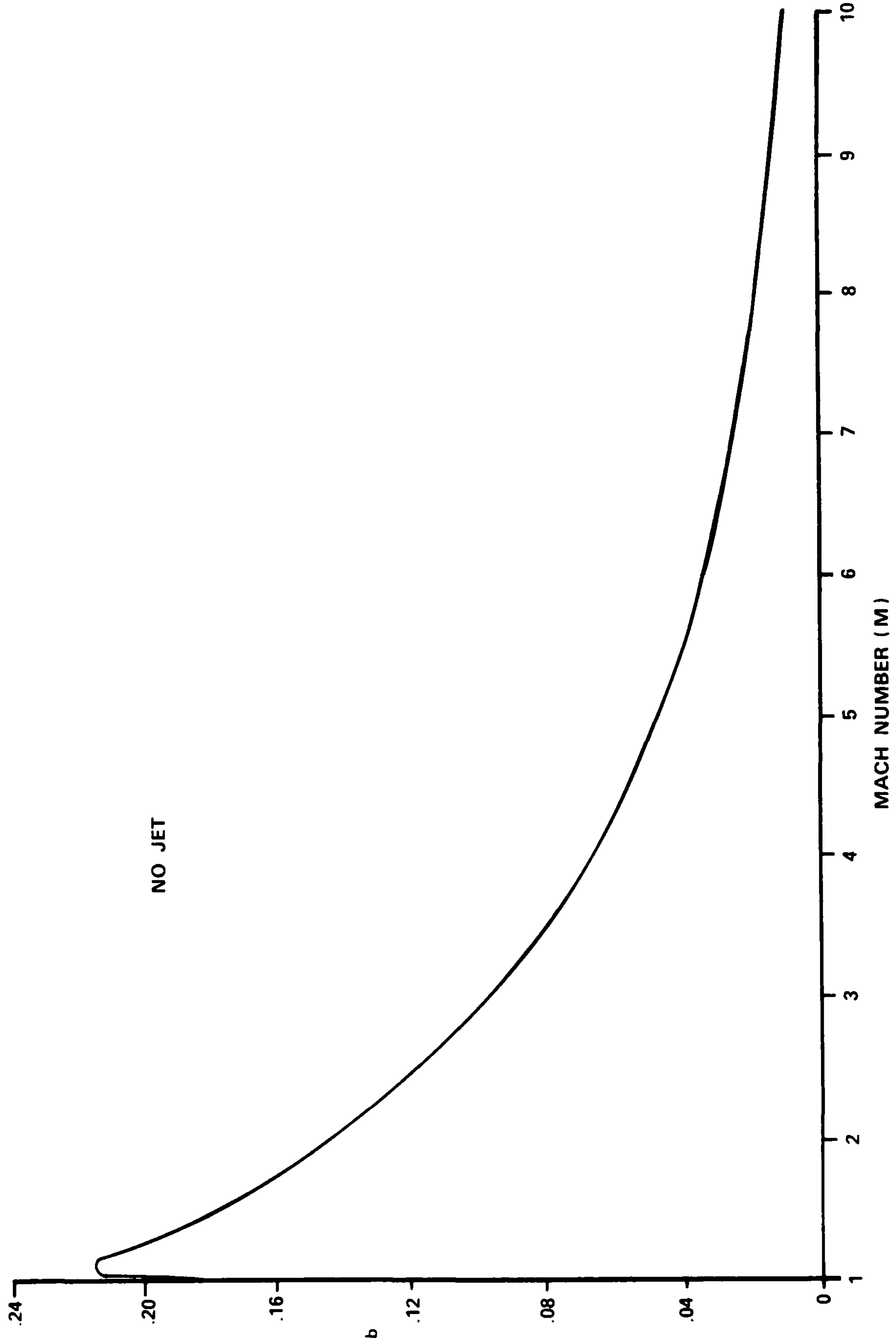


Figure A-11

BASE DRAG COEFFICIENT FOR BODIES OF REVOLUTION WITH NO BOATTAIL

(Adapted from Figure 4.2.3.1-60 of Reference [3])

iv) C_{N_q} : PITCHING DERIVATIVE

Charts based on simple Newtonian theory, are presented for determining C_{N_q} of spherical segments and cone frustums at small angles of attack.

The coefficients of these charts are referred to the body base area and base diameter and to a moment center at the forward face of the segment. By proper use of the data presented, the total C_{N_q} may be determined for bodies composed of multiple cone frustums with or without spherically blunted noses.

The Newtonian value of the derivative C_{N_q} for a complex body is obtained as follows:

Step 1: Compute C'_{N_q} for each body segment about its front face using Figures A-12 and A-13.

Step 2: Transfer the individual derivatives C'_{N_q} to a common reference axis by appling the following transfer equation to each body segment

$$C_{N_q} = C'_{N_q} - 2\left(\frac{n}{d}\right)C_{N_\alpha} \tag{A.6}$$

where

C_{N_α} is the normal-force-curve slope for each segment based on individual base areas.

C'_{N_q} is the pitching derivative for each segment based on individual base areas and base diameters and referred to a moment center at the forward face of the segment, from Figures A-12 and A-13.

n is the distance from the face of a given frustum to the desired moment reference axis of the configuration, positive aft.

d is the base diameter of a given frustum.

Step 3: The transferred derivatives of the individual body segments are converted to a common reference area and diameter and added. The total derivative is given by

$$C_{N_q} = \sum_{n=1}^{m} (C_{N_q})_n \left(\frac{d_n}{d_b}\right)^3 \qquad \text{(A.7)}$$

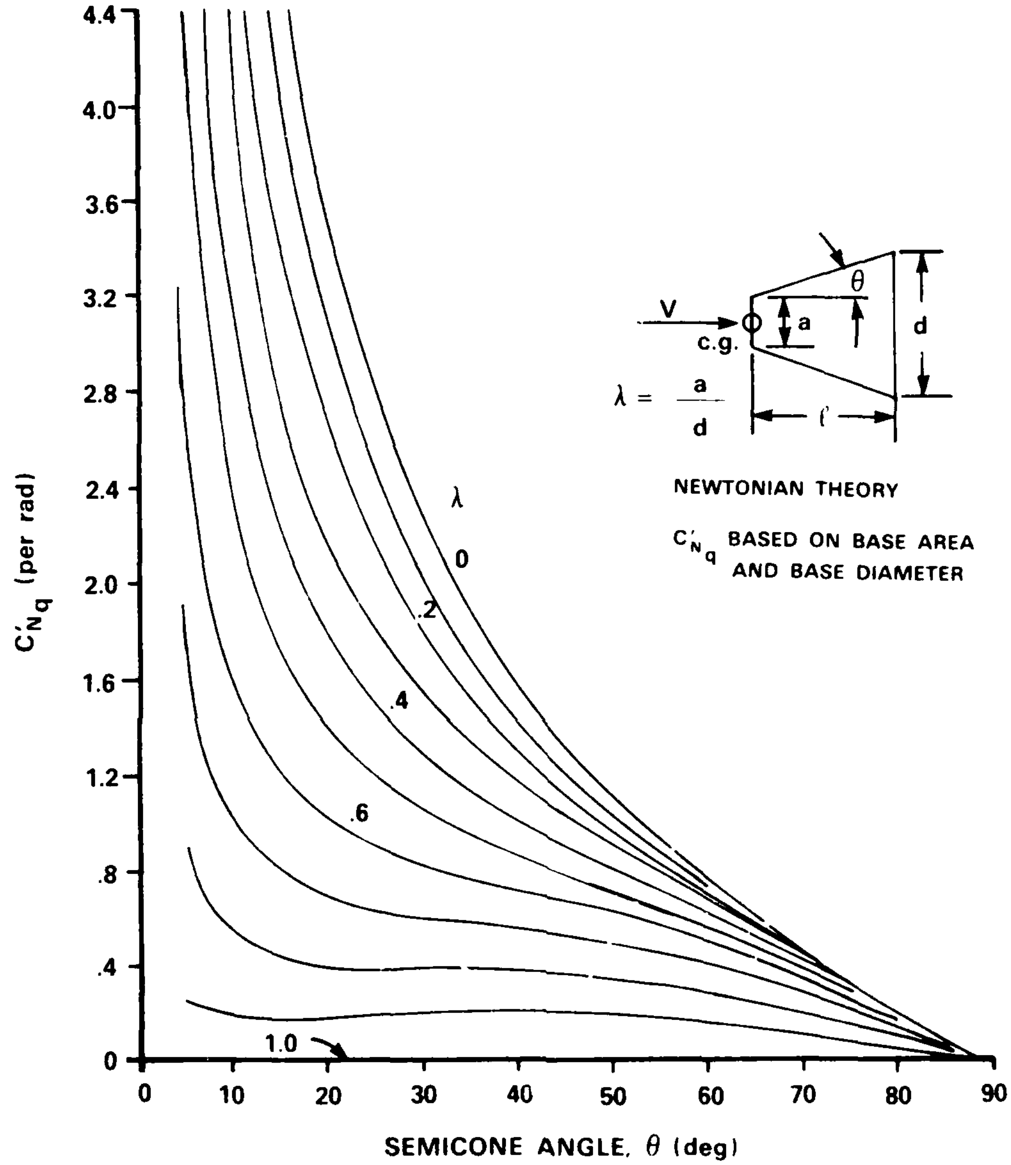


Figure A-12

PITCHING DERIVATIVE C'_{N_q} FOR CONE FRUSTUMS

(Reproduced from Figure 7.2.1.1-9a of Reference [3])

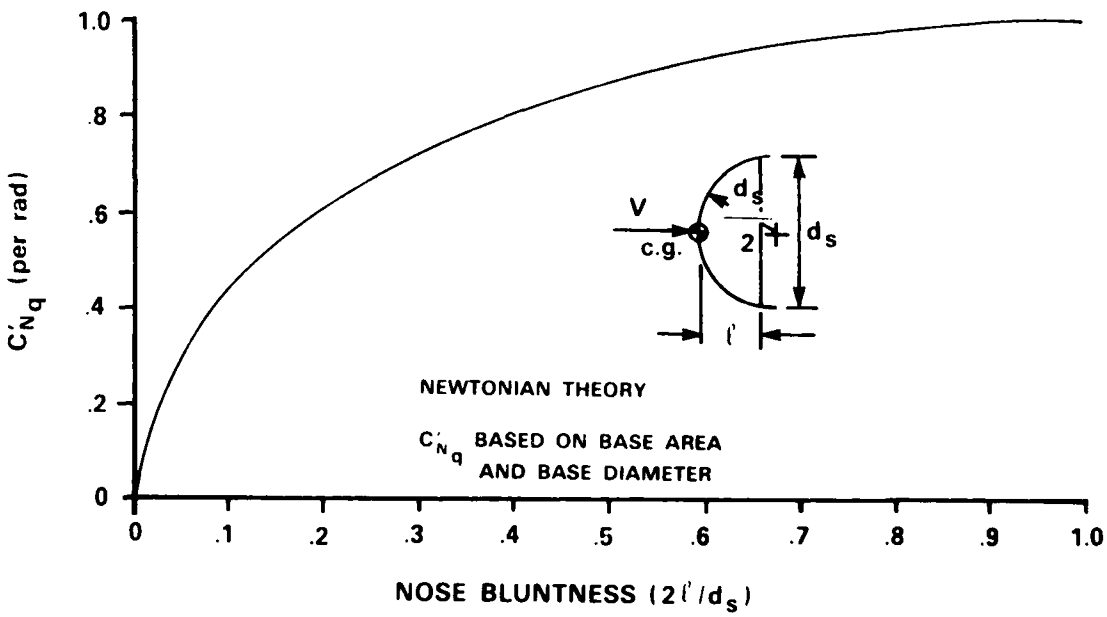


Figure A-13

PITCHING DERIVATIVE C'_{N_q} FOR SPHERICAL SEGMENTS

(Reproduced from Figure 7.2.1.1-9b of Reference [3])

v) C_{m_q} : PITCHING DERIVATIVE

Charts based on simple Newtonian theory are presented for determining C_{m_q} of spherical segments and cone frustums at small angles of attack. The coefficients of these charts are referred to the base area and the square of the base diameter and to a moment center at the forward face of the segment. By proper use of the data presented, the total C_{m_q} may be determined for bodies composed of multiple cone frustums with or without spherically blunted noses.

The Newtonian value of the stability derivative C_{m_q} for a complex body is obtained as follows:

Step 1: Compute C_{m_q}' for each body segment about its own front face using Figures A-14 and A-16 if the body has a spherically blunted nose, and Figures A-14 and A-15 if the body nose is a cone frustum.

Step 2: Transfer the individual derivatives C_{m_q}' to a common moment center by applying the following axis transfer equation to each body segment:

$$C_{m_q} = C_{m_q}' - 2\frac{n}{d}C_{m_\alpha}' + \frac{n}{d}C_{N_q} - 2\left(\frac{n}{d}\right)^2 C_{N_\alpha} \qquad (A.8)$$

where

C_{N_α} is the normal-force-curve slope for each segment based on individual base areas.

C'_{N_q} is the pitching derivative for each segment based on individual base areas and base diameters and referred to a moment center at the forward face of the segment.

C'_{m_α} is the pitching-moment-curve slope for each segment based on individual base areas and base diameters and referred to a moment center at the forward face of the segment.

C'_{m_q} is the pitching derivative for each body segment based on individual base areas and the square of base diameters and referred to a moment center at the forward face of the segment. If a complex body consists of combinations of cone frustums, the derivative for the first frustum must be obtained from Figure A-15, which accounts for the front face being exposed to the air stream. If the body has a spherically blunted nose, the derivative of the nose is obtained from Figure A-16. For subsequent frustums the derivatives are obtained from Figure A-14.

Step 3: The transferred derivatives of the individual body segments are added after being converted to a common reference area and squared diameter. The total derivative of the individual body segments is given by

$$C_{m_q} = \sum_{n=1}^{m} (C_{m_q})_n \left(\frac{d_n}{d_b}\right)^4 \qquad \text{(A.9)}$$

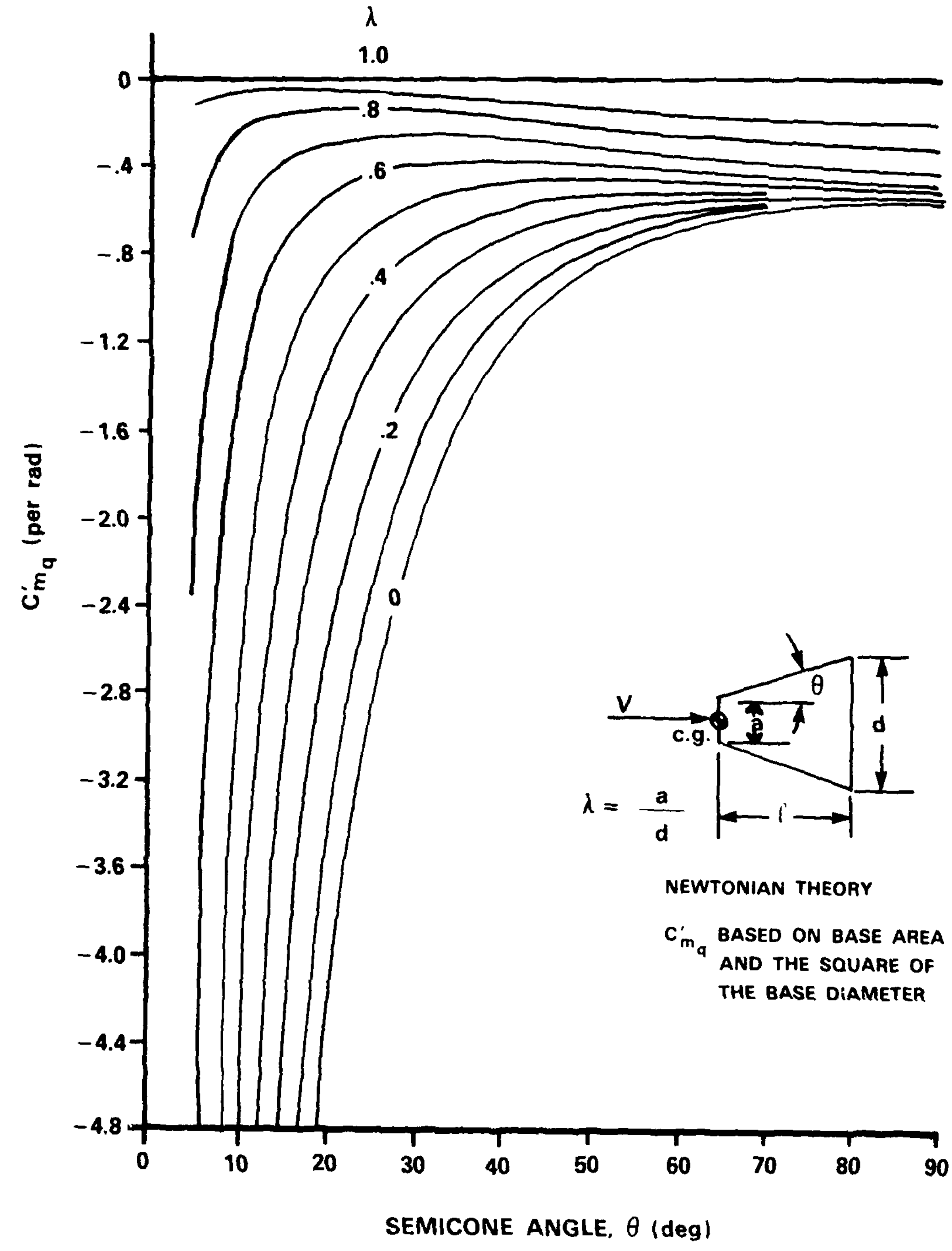


Figure A-14

PITCHING DERIVATIVE C'_{m_q} DUE TO INCLINED SIDES OF CONE FRUSTUMS
(Reproduced from Figure 7.2.1.2-12 of Reference [3])

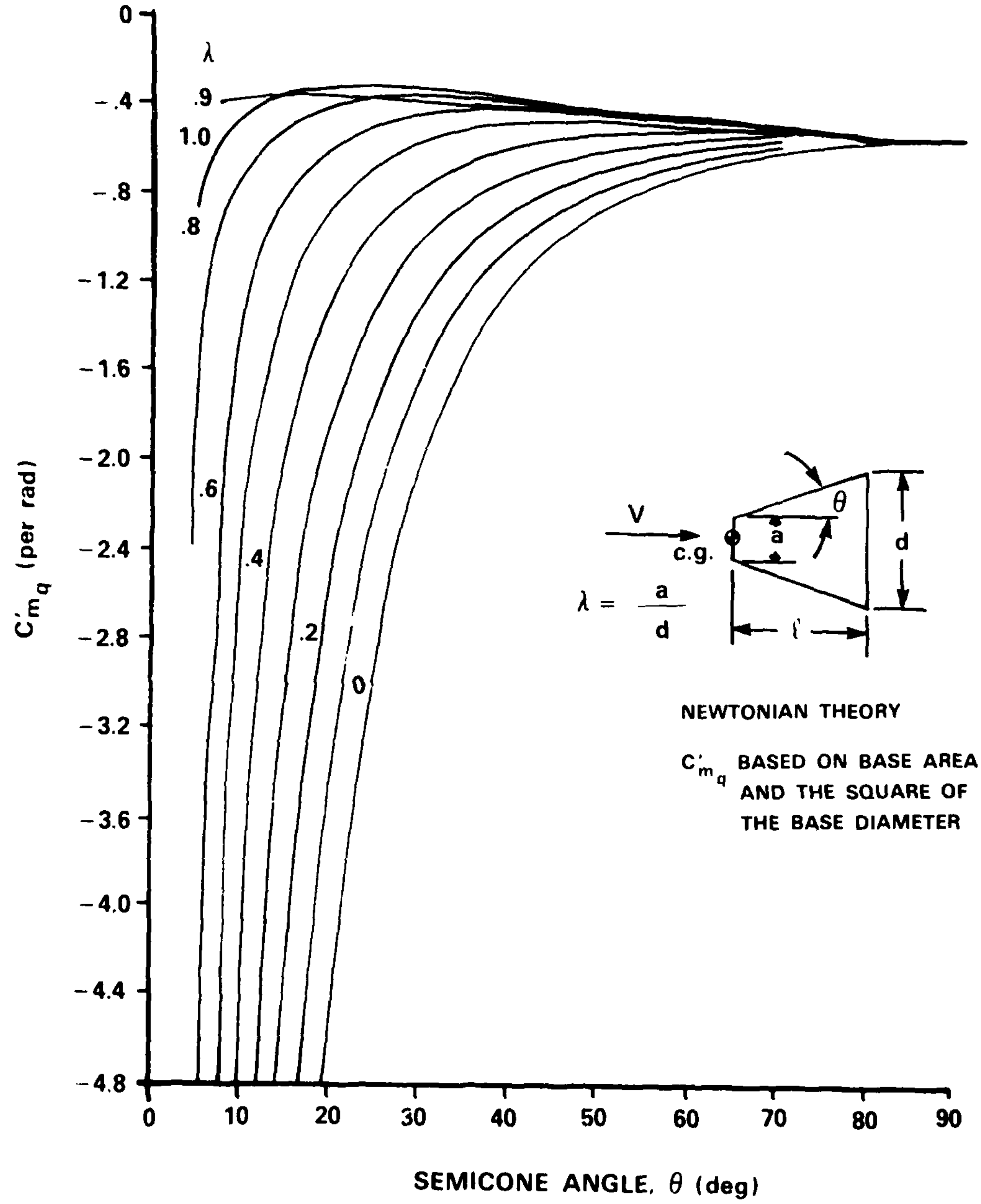


Figure A-15

PITCHING DERIVATIVE C'_{m_q} FOR CONE FRUSTUMS

(Reproduced from Figure 7.2.1.2-13a of Reference [3])

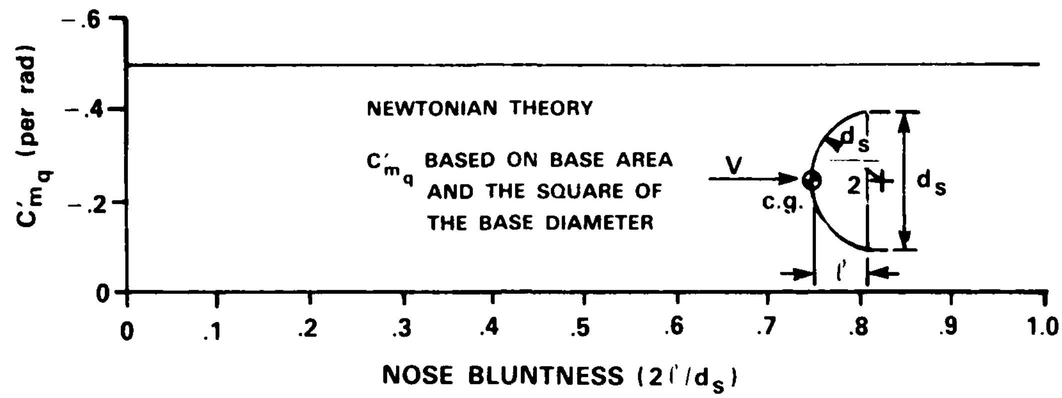


Figure A-16

PITCHING DERIVATIVE C'_{m_q} FOR SPHERICAL SEGMENTS

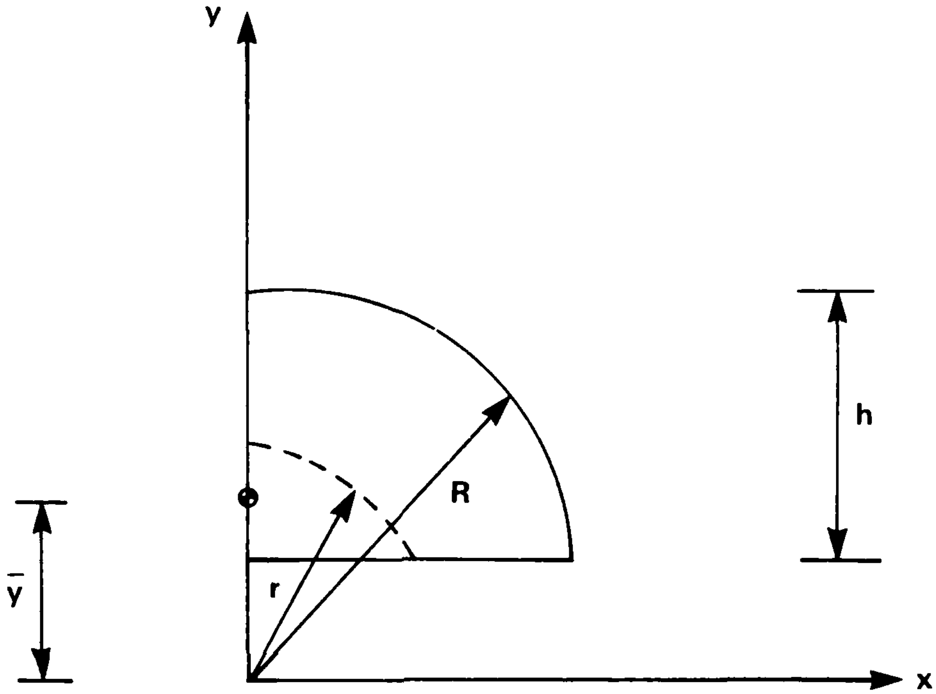
(Reproduced from Figure 7.2.1.2-13b of Reference [3])

vi) $C_{m_{\dot{\alpha}}}$: BODY ACCELERATION DERIVATIVE

The body contribution to the derivative $C_{m_{\dot{\alpha}}}$ in the hypersonic speed range is equal to zero when determined by the Newtonian Impact Theory.

APPENDIX B - SEGMENT PROPERTIES

HOLLOW SPHERICAL SEGMENT



r = INNER RADIUS OF SPHERICAL SEGMENT

R = OUTER RADIUS OF SPHERICAL SEGMENT

h = HEIGHT OF SPHERICAL SEGMENT

$\bar{y}$ = CENTROID OF SPHERICAL SEGMENT

PROPERTIES OF A SPHERICAL SEGMENT

Volume

$$V = \pi \left[Rr^2 + hR^2 - hr^2 - \frac{R^3}{3} - \frac{2r^3}{3} \right]$$

Centroid

$$\bar{y} = \frac{3 \left[(R^2-r^2)(4hR-2h^2) - (R^2-r^2)^2 \right]}{4 \left[3h\ (R^2-r^2) + 3Rr^2 - R^3 - 2r^3 \right]}$$

Axial Moment of Inertia (Taken about Y-axis)

$$I_A = \frac{M \left[\frac{8}{15} (R^5-r^5) + (R-h)(r^4-R^4) + \frac{2}{3} (R-h)^3 (R^2-r^2) \right]}{2 \left[Rr^2 + hR^2 - hr^2 - \frac{R^3}{3} - \frac{2r^3}{3} \right]}$$

Where M = Mass = Density × Volume

TRANSVERSE MOMENT OF INERTIA

(Taken Parallel to X-axis and Through the Centroid)

$$I_T = \frac{M}{\left[Rr^2 + hR^2 - hr^2 - \frac{R^3}{3} - \frac{2r^3}{3}\right]}$$

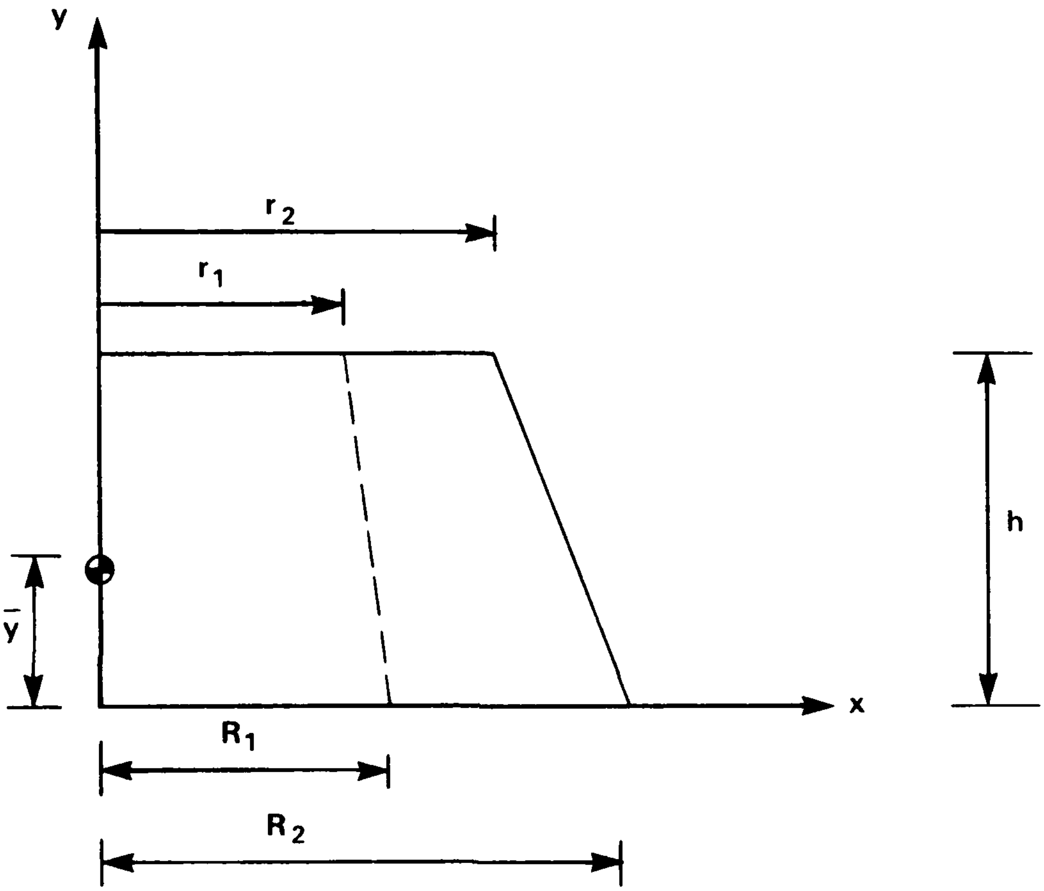
$$* \left[\frac{1}{4}(R^4-r^4)(r-R+h) + (R^2-r^2)\left\{\frac{1}{6}(r^3-(r-h)^3)\right.\right.$$

$$\left. + \bar{y}^2 (r-R+h) - \bar{y}(r^2-(R-h)^2)\right\}$$

$$+ \frac{R^4}{4}(R-r) + R^2 \left\{\frac{1}{6}(R^3-r^3) + \bar{y}^2 (R-r) - \bar{y}(R^2-r^2)\right\}$$

$$\left. - \frac{3}{20}(R^5-r^5) + \frac{\bar{y}}{2}(R^4-r^4) - \frac{\bar{y}^2}{3}(R^3-r^3)\right]$$

HOLLOW TRUNCATED CONE



r_1 = INNER RADIUS AT SMALL END OF TRUNCATED CONE

r_2 = OUTER RADIUS AT SMALL END OF TRUNCATED CONE

R_1 = INNER RADIUS AT LARGE END OF TRUNCATED CONE

R_2 = OUTER RADIUS AT LARGE END OF TRUNCATED CONE

h = SEGMENT HEIGHT

$\bar{y}$ = CENTROID

PROPERTIES OF A HOLLOW TRUNCATED CONE

Volume

$$V = \frac{\pi h}{3} \left[R_2^2 - R_1^2 + r_2^2 - r_1^2 + R_2 r_2 - R_1 r_1 \right]$$

Centroid

$$\bar{y} = \frac{h}{4} \frac{\left[R_2^2 - R_1^2 + 3r_2^2 - 3r_1^2 + 2R_2 r_2 - 2R_1 r_1 \right]}{\left[R_2^2 - R_1^2 + r_2^2 - r_1^2 + R_2 r_2 - R_1 r_1 \right]}$$

Axial Moment of Inertia (Taken about Y-axis)

$$I_A = \frac{3M}{10} \left[(R_2^4 + R_2^3 r_2 + R_2^2 r_2^2 + R_2 r_2^3 + r_2^4) \right.$$

$$\left. - (R_1^4 + R_1^3 r_1 + R_1^2 r_1^2 + R_1 r_1^3 + r_1^4) \right]$$

$$/ \left[R_2^2 - R_1^2 + r_2^2 - r_1^2 + R_2 r_2 - R_1 r_1 \right]$$

Where M = Mass = Density × Volume

TRANSVERSE MOMENT OF INERTIA

(Taken Parallel to X-axis and Through the Centroid)

$$I_T = \Big[\frac{3M}{4}\Big\{R_2^4 - 2R_2^3(R_2-r_2) + 2R_2^2(R_2-r_2)^2 - R_2(R_2-r_2)^3 + \frac{(R_2-r_2)^4}{5}$$

$$- R_1^4 + 2R_1^3(R_1-r_1) - 2R_1^2(R_1-r_1)^2 + R_1(R_1-r_1)^3 - \frac{(R_1-r_1)^4}{5}\Big\}$$

$$+ 3M\Big(h^2\Big\{\frac{R_2^2}{3} + \frac{(R_2-r_2)^2}{5} - R_2\frac{(R_2-r_2)}{2} - \frac{R_1^2}{3} - \frac{(R_1-r_1)^2}{5} + R_1\frac{(R_1-r_1)}{2}\Big\}$$

$$+ \bar{y}^2\Big\{R_2^2 + \frac{(R_2-r_2)^2}{3} - R_2(R_2-r_2) - R_1^2 - \frac{(R_1-r_1)^2}{3} + R_1(R_1-r_1)\Big\}$$

$$+ \bar{y}h\Big\{-R_2^2 - \frac{(R_2-r_2)^2}{2} + 4R_2\frac{(R_2-r_2)}{3} + R_1^2 + \frac{(R_1-r_1)^2}{2} - 4R_1\frac{(R_1-r_1)}{3}\Big\}\Big)\Big]$$

$$/\ \left[R_2^2 - R_1^2 + r_2^2 - r_1^2 + R_2r_2 - R_1r_1\right]$$

APPENDIX C - FLOW CHART AND FORTRAN LISTING OF SFFSTAB

SFFSTAB: FLOWCHART

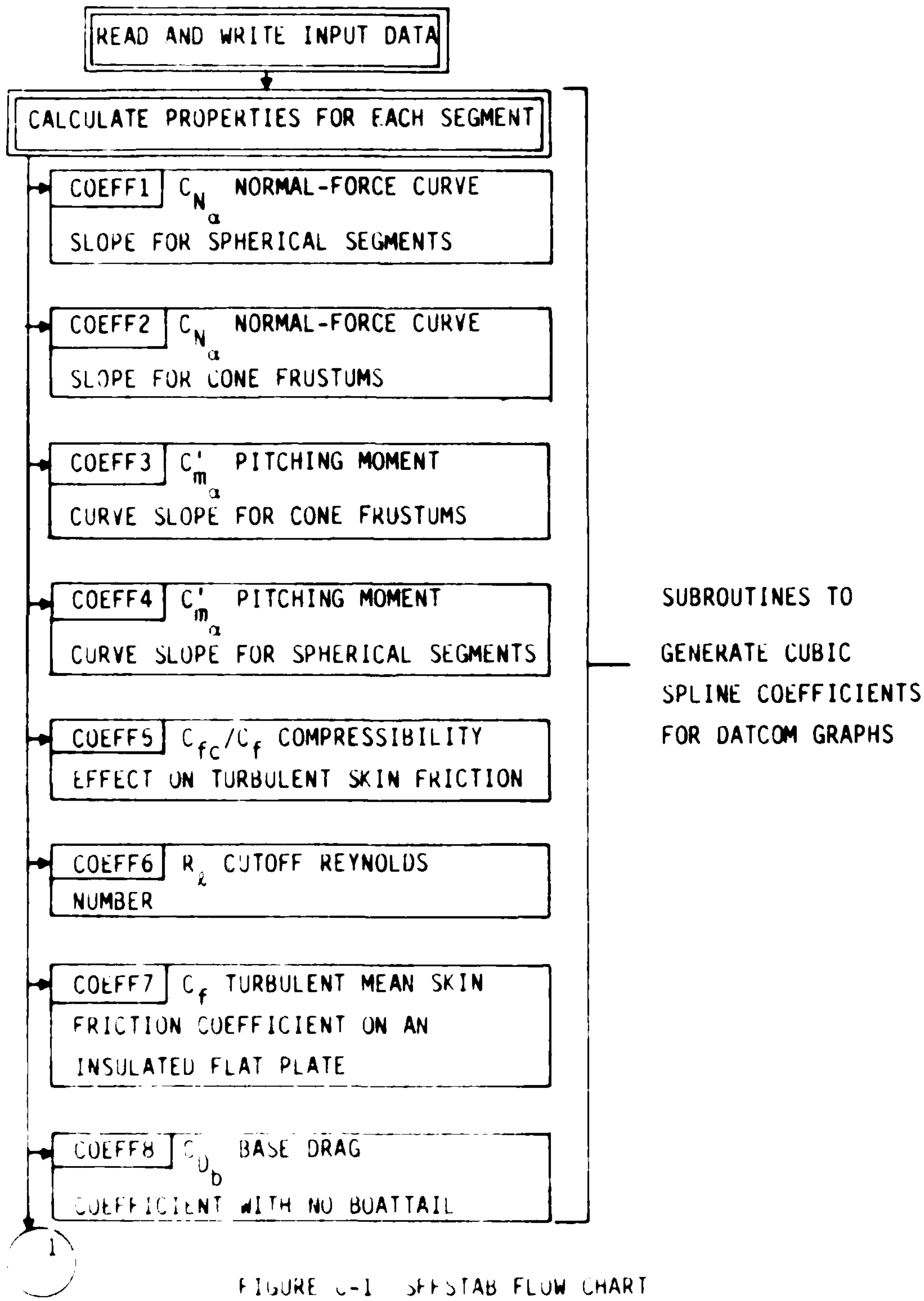


FIGURE C-1 SFFSTAB FLOW CHART

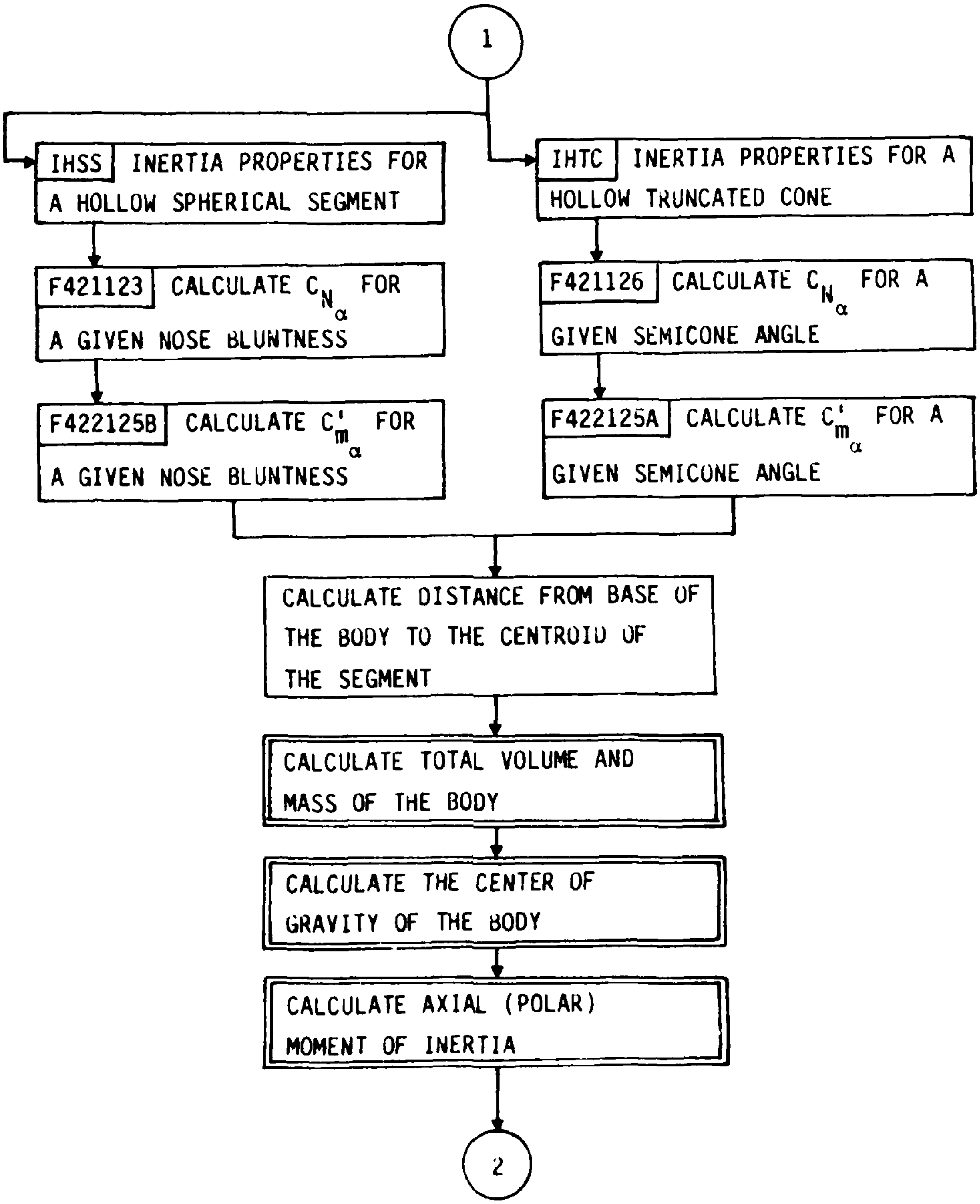


FIGURE C-2 SFFSTAB FLOWCHART CONT'D

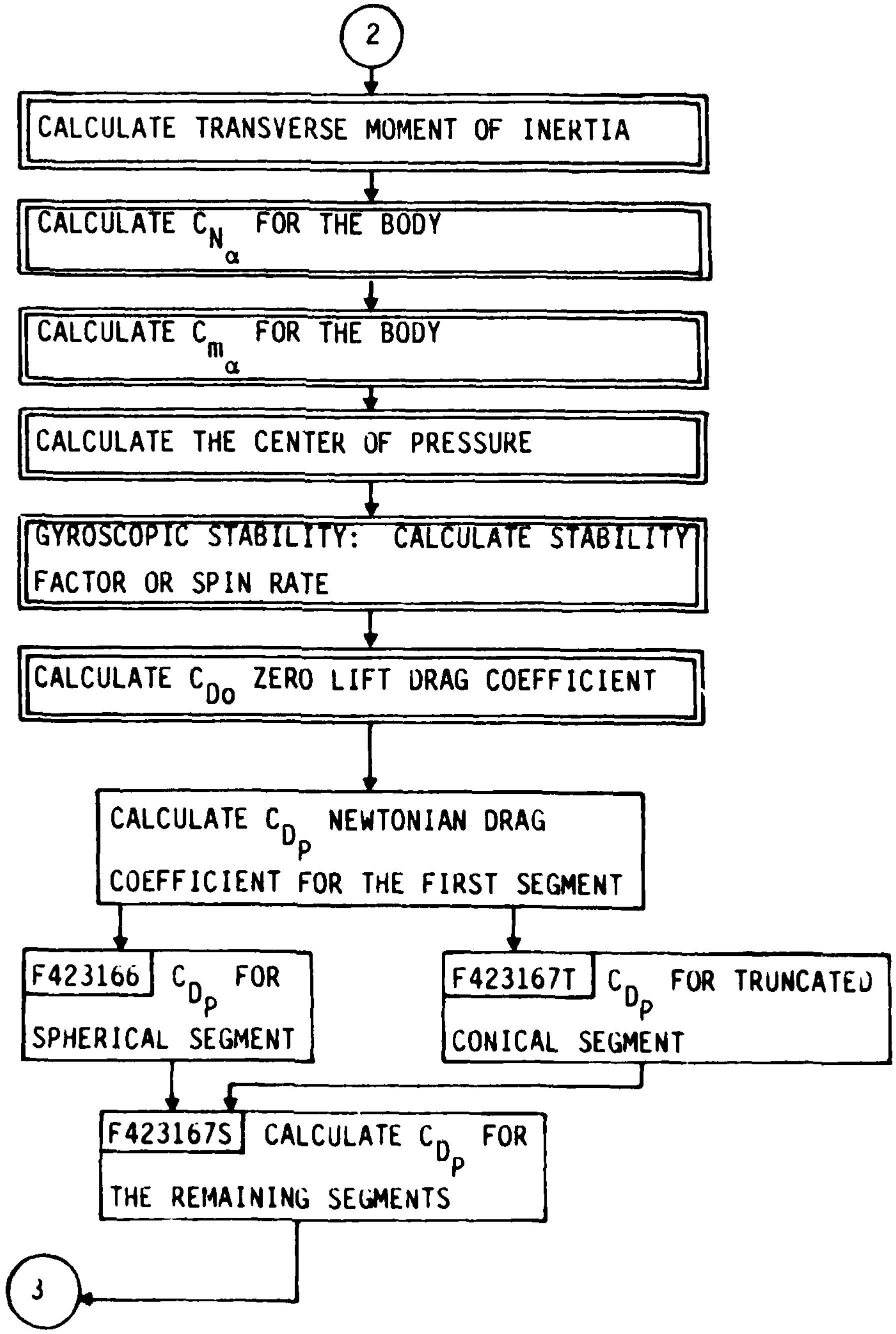


FIGURE C-3 SFFSTAB FLOW CHART CONT'D

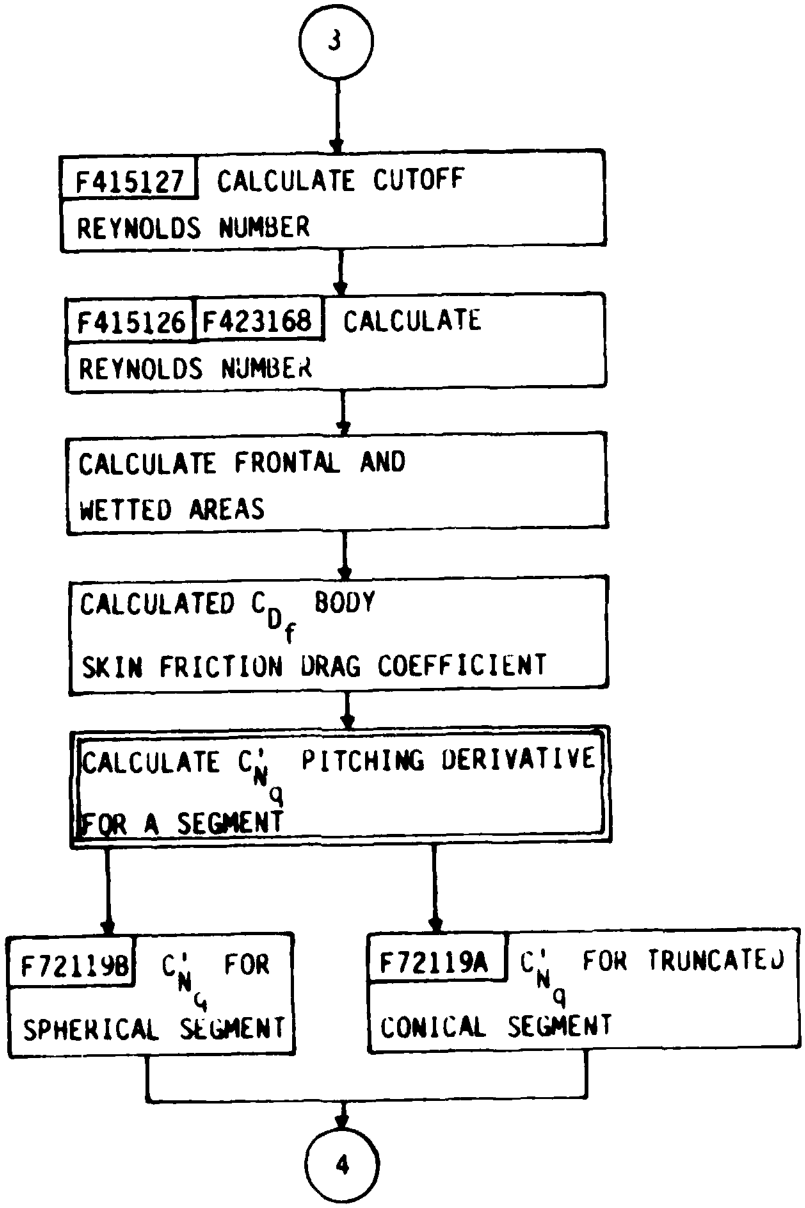


FIGURE C-4 SFFSTAB FLOWCHART CONT'D

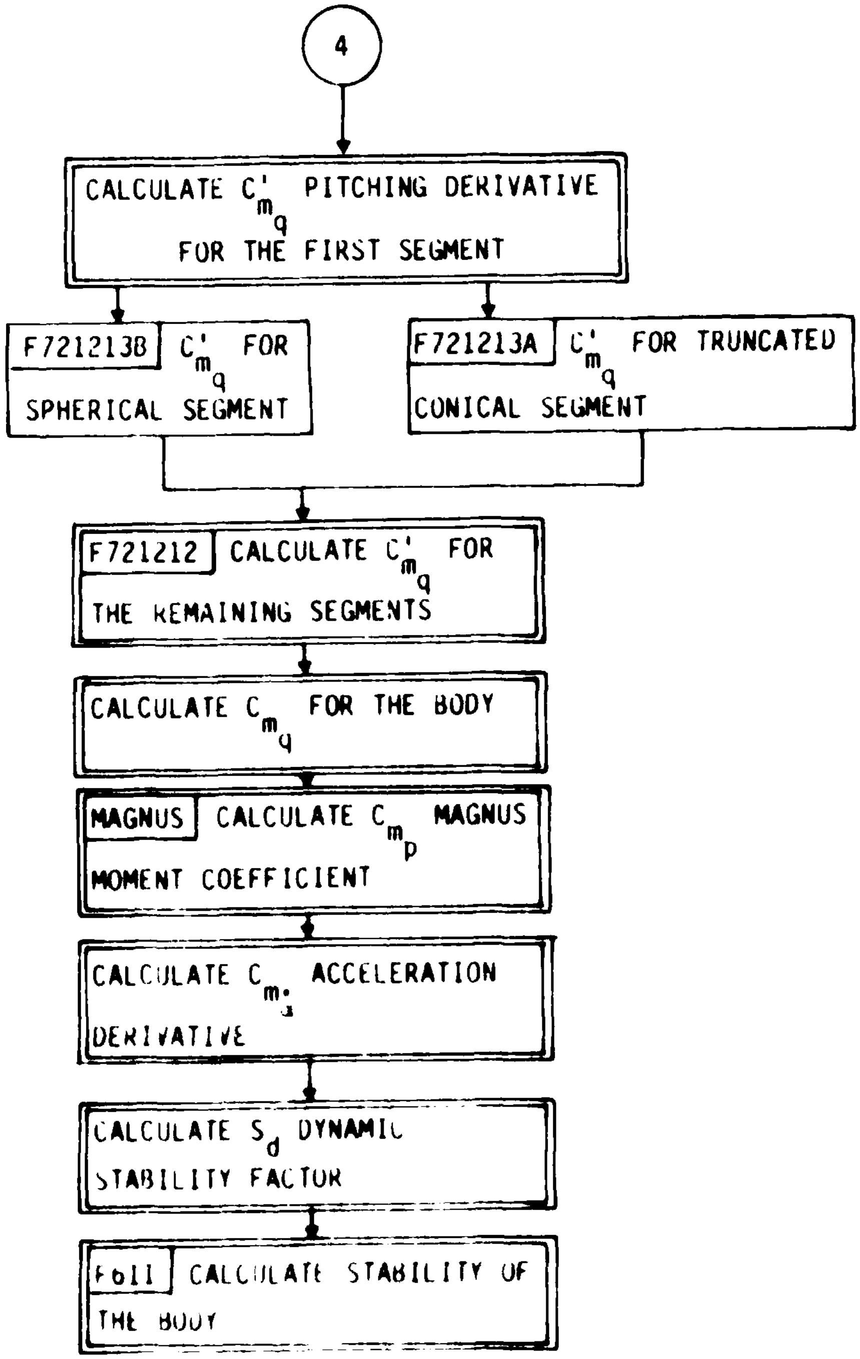


FIGURE C-5 SFFSTAB FLOW CHART CONT'D

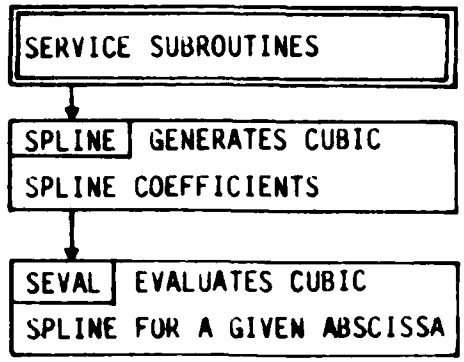


FIGURE C-6 SFFSTAB FLOWCHART CONT'D

```
C  PROGRAM TO CALCULATE GYROSCOPIC AND DYNAMIC STABILITY
C
      DIMENSION ISEG(100),R2(100),R1(100),H(100),RR2(100),RR1(100)
      DIMENSION V(100),AMASS(100),YB(100),AI(100),TI(100),CNAP(100)
      DIMENSION CMAP(100),THETA(100),AD(100),DBCS(100),DCBCS(100)
      DIMENSION DB(100),DBFS(100),DBFSRA(100),CMA(100),CMAL(100)
      DIMENSION CDP(100),AREA(100),CNQP(100),CMQP(100),CMQ(100)
      COMMON/XY1/X1(11),Y1(11)
      COMMON/XY2/X2(11,10),Y2(11,10)
      COMMON/XY3/X3(11,10),Y3(11,10)
      COMMON/XY4/X4(13),Y4(13)
      COMMON/XY5/X5(8),Y5(8)
      COMMON/XY6/X6(5),Y6(5)
      COMMON/XY7/X7(26),Y7(26)
      COMMON/XY8/X8(8),Y8(8)
      COMMON/XYB/XXB(6),YYB(6)
      COMMON/BCD1/B1(11),C1(11),D1(11)
      COMMON/BCD2/B2(11,10),C2(11,10),D2(11,10)
      COMMON/BCD3/B3(11,10),C3(11,10),D3(11,10)
      COMMON/BCD4/B4(13),C4(13),D4(13)
      COMMON/BCD5/B5(8),C5(8),D5(8)
      COMMON/BCD6/B6(5),C6(5),D6(5)
      COMMON/BCD7/B7(26),C7(26),D7(26)
      COMMON/BCD8/B8(8),C8(8),D8(8)
      COMMON/BCD3B/B3B(6),C3B(6),D3B(6)
      CHARACTER*6 TITLE(15)
C
C*************************************************************
C
C  ITYPE = 0 - SPHERICAL SEGMENT AND TRUNCATED CONES ARE USED
C          1 - ONLY TRUNCATED CONES ARE USED
C  DEN = DENSITY OF MATERIAL (MASS/VOLUME)(LB SEC**2/IN**4)
C  NSEG = NUMBER OF SEGMENTS
C  DBCS = DISTANCE FROM BASE OF BODY TO CENTROID OF SEGMENT
C  TVOL = TOTAL VOLUME OF BODY(IN**3)
C  TMASS = TOTAL MASS OF BODY(LB SEC**2/IN)
C  CGOB = CENTER OF GRAVITY OF BODY (RELATIVE TO BASE)
C  AIB = AXIAL (POLAR) MOMENT OF INERTIA OF THE BODY(LB SEC**2 IN)
C  TIB = TRANSVERSE MOMENT OF INERTIA OF THE BODY(LB SEC**2 IN)
C  DCBCS = DISTANCE FROM CENTROID OF BODY TO CENTROID OF SEGMENT
C  DB = BASE DIAMETER OF THE SEGMENT
C  CNAT = TOTAL CNA FOR THE BODY
C  CMAT = TOTAL CMA FOR THE BODY (BASED ON AREA AND BASE DIAMETER)
C  CMATL = TOTAL CMA FOR THE BODY (BASED ON AREA AND BODY LENGTH)
C  RA = DISTANCE FROM MOMENT REFERENCE AXIS TO BASE OF BODY
C       (IF RA = 0.0 THE C OF G OF THE BODY IS USED)
C  DBFS = DISTANCE FROM BASE OF BODY TO FRONT FACE OF SEGMENT
C  DBFSRA = DISTANCE FROM FRONT FACE OF SEGMENT TO MOMENT REFERENCE
C           AXIS
C  CMA = CMA FOR A SEGMENT , REFERRED TO A COMMON REFERENCE AXIS
C        (BASED ON AREA AND BASE DIAMETER)
C  CMAL = CMA FOR A SEGMENT , REFERRED TO A COMMON REFERENCE AXIS
C        (BASED ON AREA AND SEGMENT LENGTH)
C  BL = LENGTH OF BODY
```

```
C  XCP = CENTER OF PRESSURE AS A FRACTION OF BODY LENGTH
C  XM = MOMENT CENTER LOCATION AS A FUNCTION OF BODY LENGTH
C  RHO = AIR DENSITY(LB SEC**2/IN**4)
C  W = SPIN RATE (RAD/SEC)
C  VEL = PROJECTILE VELOCITY(IN/SEC)
C  ISG = 1 - CALCULATE W
C        0 - CALCULATE SG
C  SG = GYROSCOPIC STABILITY FACTOR
C  CDP = NEWTONIAN DRAG COEFFICIENT
C  BLUNT = NOSE BLUNTNESS FOR A SPHERICAL SEGMENT
C  ESR = EQUIVALENT SAND ROUGHNESS(IN)
C  RE = REYNOLDS NUMBER (BASED ON L )
C  RES = SAME AS RE
C  CRE = CUTOFF REYNOLDS NUMBER
C  AR = ADMISSIBLE ROUGHNESS
C  U = ABSOLUTE VISCOSITY(LB SEC/IN**2)
C  CF = INCOMPRESSIBLE FLAT PLATE SKIN FRICTION COEFFICIENT
C  CFCCF = RATIO OF COMPRESSIBLE TO INCOMPRESSIBLE SKIN FRICTION
C          COEFFICIENT
C  SB = BODY MAXIMUM FRONTAL AREA(IN**2)
C  SS = WETTED AREA OR SURFACE AREA OF THE BODY EXCLUDING THE BASE
C  CDF = BODY SKIN FRICTION DRAG COEFFICIENT
C  CD0 = ZERO LIFT DRAG COEFFICIENT
C  CDB = BASE DRAG COEFFICIENT
C  AREA = SUFACE AREA OF A SEGMENT
C  CNQP = PITCHING DERIVATIVE FOR A SEGMENT
C  CMAP = PITCHING MOMENT CURVE SLOPE FOR A SEGMENT
C  CNAP = NORMAL FORCE CURVE SLOPE FOR A SEGMENT
C  CMQP = PITCHING DERIVATIVE FOR SEGMENT
C  CMQ = PITCHING DERVATIVE TRANSFERRED TO A COMMON AXIS
C  CMQT = PITCHING DERIVATIVE FOR BODY
C  CMPA = DERIVATIVE OF THE MAGNUS MOMENT COEFFICIENT
C  CMAD = ACCELERATION DERIVATIVE
C  SD = DYNAMIC STABILITY FACTOR
C  AKB = DIMENSIONLESS AXIAL RADIUS OF GYRATION
C  TKB = DIMENSIONLESS TRANSVERSE RADIUS OF GYRATION
C  DMCP = DISTANCE FROM MAGNUS CENTER OF PRESSURE TO CENTER OF GRAVITY
C  ISPIN = 1 - READ LINER DATA
C  TAM = TOTAL ANGULAR MOMENTUM (LB SEC IN)
C  WL = SPIN RATE OF LINER (RAD/SEC)
C  RPML = SPIN RATE OF LINER (RPM)
C  NLS = NUMBER OF LINER SEGMENTS
C  TLS = THICKNESS OF LINER SEGMENT
C  HLS = HEIGHT OF LINER SEGMENT
C  RCS = RADIUS TO CENTROID OF CROSS-SECTIONAL AREA OF LINER SEGMENT
C  AMASSL = MASS OF LINER SEGMENT
C  TMASSL = TOTAL MASS OF THE LINER
C
C***********************************************************
C
C  READ AND WRITE INPUT DATA
C
      READ(5,900)(TITLE(I),I=1,15)
  900 FORMAT(13A6,2A1)
```

```
      WRITE(6,801)(TITLE(I),I=1,15)
  801 FORMAT(1H ,///,5X,13A6,2A1,//)
      READ(5,10)DEN
   10 FORMAT(F10.5)
      READ(5,15)ITYPE,NSEG
   15 FORMAT(2I5)
      IF(ITYPE.EQ.1)GO TO 20
      READ(5,25)ISEG(1),R2(1),R1(1),H(1)
   25 FORMAT(I5,5X,3F10.5)
      DO 30 I=2,NSEG
      READ(5,35)ISEG(I),RR2(I),RR1(I),R2(I),R1(I),H(I)
   35 FORMAT(I5,5X,5F10.5)
   30 CONTINUE
      GO TO 40
   20 DO 45 I=1,NSEG
      READ(5,35)ISEG(I),RR2(I),RR1(I),R2(I),R1(I),H(I)
   45 CONTINUE
   40 WRITE(6,46)
   46 FORMAT(1H1,10X,'***** GYROSCOPIC STABILITY DATA *****',//)
      WRITE(6,50)DEN,ITYPE,NSEG
   50 FORMAT(1H ,5X,'DENSITY =',F15.8,5X,'ITYPE =',I5,5X,
     1 'NUMBER OF SEGMENTS =',I5)
      WRITE(6,55)
   55 FORMAT(1H ,7X,'ISEG',9X,'RR2',12X,'RR1',13X,'R2',13X,
     1 'R1',13X,'H',/)
      IF(ITYPE.EQ.1)GO TO 60
      WRITE(6,65)ISEG(1),R2(1),R1(1),H(1)
   65 FORMAT(1H ,5X,I5,30X,3(5X,F10.5))
      DO 70 I=2,NSEG
      WRITE(6,75)ISEG(I),RR2(I),RR1(I),R2(I),R1(I),H(I)
   75 FORMAT(1H ,5X,I5,5(5X,F10.5))
   70 CONTINUE
      GO TO 80
   60 DO 90 I=1,NSEG
      WRITE(6,75)ISEG(I),RR2(I),RR1(I),R2(I),R1(I),H(I)
   90 CONTINUE
   80 READ(5,210)RA
  210 FORMAT(F10.5)
      READ(5,295)ISG
  295 FORMAT(I5)
      WRITE(6,400)RA,ISG
  400 FORMAT(1H ,5X,'REFERENCE AXIS =',F10.5,5X,'ISG =',I5)
      IF(ISG.EQ.1)GO TO 300
      READ(5,305)W,RHO,VEL
  305 FORMAT(3F10.5)
      WRITE(6,405)W,RHO,VEL
  405 FORMAT(1H ,5X,'W =',F20.10,5X,'RHO =',F20.15,5X,'VELOCITY =',
     1 F15.5)
      GO TO 420
  300 READ(5,305)SG,RHO,VEL
      WRITE(6,410)SG,RHO,VEL
  410 FORMAT(1H ,5X,'SG =',F10.5,5X,'RHO =',F20.15,5X,'VELOCITY =',
     1 F15.5)
C
```

```
C  CALCULATE PROPERTIES FOR EACH SEGMENT
C
  420 CALL COEFF1
      CALL COEFF2
      CALL COEFF3
      CALL COEFF4
      CALL COEFF5
      CALL COEFF6
      CALL COEFF7
      CALL COEFF8
      DO 100 I=1,NSEG
      IF(I.GT.1)GO TO 105
      IF(ITYPE.EQ.1)GO TO 105
      CALL IHSS(ISEG(1),R2(1),R1(1),H(1),DEN,V(1),AMASS(1),YB(1),
     1 B,AI(1),TI(1))
      YB(1)=B
      BLUNT=H(1)/R2(1)
      CALL F421123(BLUNT,CNAP(1))
      CALL F422125B(BLUNT,CMAP(1))
      WRITE(6,110)BLUNT,CNAP(1),CMAP(1)
  110 FORMAT(1H ,5X,'NOSE BLUNTNESS =',F10.5,5X,'CNAP =',F10.5,
     1 5X,'CMAP =',F10.5,//)
      GO TO 100
  105 CALL IHTC(ISEG(I),RR2(I),RR1(I),R2(I),R1(I),H(I),DEN,V(I),
     1 AMASS(I),YB(I),AI(I),TI(I))
      AD(I)=R2(I)/RR2(I)
      THETA(I)=ATAN((RR2(I)-R2(I))/H(I))/3.14159265*180.
      CALL F421126(THETA(I),CNAP(I),AD(I))
      CALL F422125A(THETA(I),CMAP(I),AD(I))
      WRITE(6,115)THETA(I),AD(I),CNAP(I),CMAP(I)
  115 FORMAT(1H ,5X,'THETA =',F10.5,5X,'A/D =',F10.5,5X,
     1 'CNAP =',F10.5,5X,'CMAP =',F10.5,//)
  100 CONTINUE
C
C  CALCULATE DISTANCE FROM BASE OF BODY TO CENTROID OF SEGMENT
C
      SUM1=H(NSEG)
      NSEGM1=NSEG-1
      DBCS(NSEG)=YB(NSEG)
      DO 120 I=1,NSEGM1
      DBCS(NSEG-I)=YB(NSEG-I)+SUM1
      SUM1=SUM1+H(NSEG-I)
  120 CONTINUE
C
C  CALCULATE THE TOTAL VOLUME AND TOTAL MASS OF BODY
C
      TVOL=0.0
      TMASS=0.0
      DO 125 I=1,NSEG
      TVOL=TVOL+V(I)
      TMASS=TMASS+AMASS(I)
  125 CONTINUE
C
C  CALCULATE CENTER OF GRAVITY OF BODY (RELATIVE TO BASE)
```

```
C
      SUM2=0.0
      DO 130 I=1,NSEG
      SUM2=SUM2+DBCS(I)*V(I)
  130 CONTINUE
      CGOB=SUM2/TVOL
C
C  CALCULATE AXIAL (POLAR) MOMENT OF INERTIA
C
      AIB=0.0
      DO 135 I=1,NSEG
      AIB=AIB+AI(I)
  135 CONTINUE
C
C  CALCULATE DISTANCE FROM CG OF BODY CG OF SEGMENT
C
      DO 140 I=1,NSEG
      DCBCS(I)=ABS(DBCS(I)-CGOB)
  140 CONTINUE
C
C  CALCULATE TRANSVERSE MOMENT OF INERTIA USING PARALLEL AXIS THEOREM
C
      TIB=0.0
      DO 145 I=1,NSEG
      TIB=TIB+TI(I)+AMASS(I)*DCBCS(I)**2.
  145 CONTINUE
C
C  CALCULATE BASE DIAMETER OF EACH SEGMENT
C
      DO 195 I=1,NSEG
      IF(I.GT.1)GO TO 190
      IF(ITYPE.EQ.1)GO TO 190
      DB(1)=2.*(H(1)*(2.*R2(1)-H(1)))**.5
      GO TO 195
  190 DB(I)=2.*RR2(I)
  195 CONTINUE
      WRITE(6,150)
  150 FORMAT(1H ,6X,'ISEG',8X,'DBCS',11X,'DCBCS',12X,'DB')
      DO 155 I=1,NSEG
      WRITE(6,160)ISEG(I),DBCS(I),DCBCS(I),DB(I)
  160 FORMAT(1H ,5X,I5,3(5X,F10.5))
  155 CONTINUE
      WRITE(6,165)TVOL
  165 FORMAT(1H ,5X,'TOTAL VOLUME OF BODY =',F10.5)
      WRITE(6,170)TMASS
  170 FORMAT(1H ,5X,'TOTAL MASS OF BODY =',F10.5)
      WRITE(6,175)CGOB
  175 FORMAT(1H ,5X,'CENTER OF GRAVITY OF BODY (RELATIVE TO BASE
     1 F10.5)
      WRITE(6,180)AIB
  180 FORMAT(1H ,5X,'AXIAL MOMENT OF INERTIA OF BODY   ,F10.5
      WRITE(6,185)TIB
  185 FORMAT(1H ,5X,'TRANSVERSE MOMENT OF INERTIA OF BODY   ,F10.5
C
```

```
C  CALCULATE CNA FOR THE BODY
C
      CNAT=0.0
      DO 200 I=1,NSEG
      CNAT=CNAT+CNAP(I)*(DB(I)/DB(NSEG))**2.
  200 CONTINUE
      WRITE(6,205)CNAT
  205 FORMAT(1H ,5X,'CNA FOR THE BODY =',F10.5)
C
C  CALCULATE DISTANCE FROM BASE OF BODY TO FRONT FACE OF SEGMENT
C
      SUM3=0.0
      DO 215 I=1,NSEG
      DBFS(NSEG+1-I)=SUM3+H(NSEG+1-I)
      SUM3=SUM3+H(NSEG+1-I)
  215 CONTINUE
C
C  CALCULATE DISTANCE FROM SEGMENT FRONT FACE TO MOMENT REFERENCE AXIS
C
      IF(RA.EQ.0.0)RA=CGOB
      DO 220 I=1,NSEG
      DBFSRA(I)=DBFS(I)-RA
  220 CONTINUE
C
C  CALCULATE CMA FOR EACH SEGMENT(BASED ON AREA AND BASE DIAMETER)
C
      DO 225 I=1,NSEG
      CMA(I)=CMAP(I)+DBFSRA(I)/DB(I)*CNAP(I)
  225 CONTINUE
C
C  CALCULATE CMA FOR EACH SEGMENT(BASED ON AREA AND SEGMENT LENGTH)
C
      DO 510 I=1,NSEG
      CMAL(I)=CMAP(I)*DB(I)/H(I)+DBFSRA(I)/H(I)*CNAP(I)
  510 CONTINUE
C
C  CALCULATE CMA FOR THE BODY(BASED ON AREA AND BASE DIAMETER)
C
      CMAT=0.0
      DO 230 I=1,NSEG
      CMAT=CMAT+CMA(I)*(DB(I)/DB(NSEG))**3.
  230 CONTINUE
C
C  CALCULATE THE LENGTH OF THE BODY
C
      BL=0.0
      DO 235 I=1,NSEG
      BL=BL+H(I)
  235 CONTINUE

   CALCULATE CMA FOR THE BODY(BASED ON AREA AND BODY LENGTH)

      CMAT=0.0
      DO 240 I=1,NSEG
```

```
      CMATL=CMATL+CMAL(I)*(DB(I)/DB(NSEG))**2.*(H(I)/BL)
  500 CONTINUE
C
C  CALCULATE THE CENTER OF PRESSURE
C
      XM=(BL-RA)/BL
      XCP=XM-CMATL/CNAT
      WRITE (6,240)
  240 FORMAT(1H ,6X,'ISEG',8X,'DBFS',10X,'DBFSRA',12X,'CMA',11X,
     1 'CMAL',/)
      DO 245 I=1,NSEG
      WRITE(6,250)ISEG(I),DBFS(I),DBFSRA(I),CMA(I),CMAL(I)
  250 FORMAT(1H ,5X,I5,4(5X,F10.5))
  245 CONTINUE
      WRITE(6,255)CNAT
  255 FORMAT(1H ,5X,'TOTAL CNA FOR THE BODY =',F10.5)
      WRITE(6,260)CMAT
  260 FORMAT(1H ,5X,'TOTAL CMA FOR THE BODY (BASED ON AREA AND ',
     1 'BASE DIAMETER =',F10.5)
      WRITE(6,505)CMATL
  505 FORMAT(1H ,5X,'TOTAL CMA FOR THE BODY (BASED ON AREA AND ',
     1 'BODY LENGTH =',F10.5)
      WRITE(6,265)BL
  265 FORMAT(1H ,5X,'LENGTH OF THE BODY =',F10.5)
      WRITE(6,270)XCP
  270 FORMAT(1H ,5X,'CENTER OF PRESSURE AS A FRACTION OF BODY ',
     1 'LENGTH =',F10.5)
C
C  CALCULATE GYROSCOPIC STABILITY AND SPIN RATE
C
      PI=3.14159265
      IF(ISG.EQ.0)GO TO 275
      W=(SG*PI*RHO*TIB*ABS(CMAT)*DB(NSEG)**3./(2.*AIB**2.))**.5*VEL
      RPM=W*30/PI
      WRITE(6,280)W,RPM
  280 FORMAT(1H ,5X,'SPIN RATE (RAD/SEC) =',F15.5,5X,
     1 'SPIN RATE (RPM) =',F15.5)
      GO TO 285
  275 SG=2.*AIB**2.*(W/VEL)**2./(PI*RHO*TIB*CMAT*DB(NSEG)**3.)
      WRITE(6,290)SG
  290 FORMAT(1H ,5X,'GYROSCOPIC STABILITY FACTOR =',F10.5)
      WRITE(6,310)RHO,VEL
  310 FORMAT(1H ,5X,'AIR DENSITY =',F10.5,5X,'PROJECTILE VELOCITY =',
     1 F10.5)
C
C  CALCULATE CDP FOR THE FIRST SEGMENT
C
C  SPHERICAL FIRST SEGMENT

  285 IF(ITYPE.EQ.1)GO TO 600
      CALL F423166(BLUNT,CDP(1))
      GO TO 605

    NICAL (TRUNCATED) FIRST SEGMENT
```

```
[illegible]

      [illegible]

[illegible]
      [illegible]
[illegible] CONTINUE
      [illegible]
[illegible] FORMAT [illegible]

      [illegible] NUMBER

      [illegible]
      [illegible]

      CALCULATE [illegible] NUMBER

      [illegible]
      [illegible]
      IF [illegible]
      CALL F415[illegible](RE,CF)
      CALL F4231[illegible](V[illegible],CFCCF)
C
C  CALCULATE FRONTAL AND WETTED AREAS
C
      PI=3.1415926
      SB=PI*DB(NSEG)*DB(NSEG)/4
      IF(ITYPE.EQ.1)GO TO 620
      AREA(1)=2.*PI*R2(1)*H(1)
      GO TO 625
  620 AREA(1)=PI*((RR2(1)-R2(1))**2.+H(1)*H(1))**.5*(RR2(1)+R2(1))
  625 DO 630 I=2,NSEG
      AREA(I)=PI*((RR2(I)-R2(I))**2.+H(I)*H(I))**.5*(RR2(I)+R2(I))
  630 CONTINUE
      SS=0.0
      DO 635 I=1,NSEG
      SS=SS+AREA(I)
  635 CONTINUE
C
C  CALCULATE CDF, BODY SKIN FRICTION DRAG COEFFICIENT
C
      CDF=1.02*CF*CFCCF*SS/SB
C
C  CALCULATE CDO, ZERO LIFT DRAG COEFFICIENT
C
      SUMD=0.0
      DO 640 I=1,NSEG
      SUMD=SUMD+CDP(I)*(DB(I)/DB(NSEG))**2.
  640 CONTINUE
      CALL F423160(VEL,CDB)
      CDO=CDF+SUMD+CDB
C
C  CALCULATE CNQP,PITCHING DERIVATIVE FOR SEGMENT
```

```
C  BASED ON BASE AREAS AND BASE DIAMETERS REFFERRED TO FORWARD
C  FACE OF SEGMENT
C
      IF (ITYPE.EQ.1) GO TO 645
      CALL F72[illegible]B(BLUNT,CNQP(1))
      GO TO 65[illegible]
 645  CALL F72[illegible]A(THETA(1),AD(1),CNQP(1))
 650  DO 655 I=2,NSEG
      CALL F72[illegible]A(THETA(I),AD(I),CNQP(I))
 655  CONTINUE
C
C  CALCULATE CMQP, PITCHING DERIVATIVE FOR SEGMENT
C  BASED ON BASE AREAS AND SQUARE OF BASE DIAMETERS
C  REFERRED TO FORWARD FACE OF THE SEGMENT
C
      IF (ITYPE.EQ.1) GO TO 660
      CALL F7212[illegible]B(CMQP(1))
      GO TO 665
 660  CALL F72121[illegible]A(THETA(1),AD(1),CMQP(1))
 665  DO 670 I=2,NSEG
      CALL F722212(THETA(I),AD(I),CMQP(I))
 670  CONTINUE
C
C  TRANSFER THE INDIVIDUAL DERIVATIVES TO A COMMON MOMENT CENTER
C
      DO 675 I=1,NSEG
      R=DBFSRA(I)/DB(I)
      CMQ(I)=CMQP(I)-2.*R*CMAP(I)+R*CNQP(I)-2.*R*R*CNAP(I)
 675  CONTINUE
C
C  CALCULATE CMQ FOR THE ENTIRE BODY
C  BASED ON A COMMON REFERENCE AREA AND SQUARED DIAMETER
C
      CMQT=0.0
      DO 680 I=1,NSEG
      CMQT=CMQT+CMQ(I)*(DB(I)/DB(NSEG))**4
 680  CONTINUE
C
C  CALCULATE THE MAGNUS MOMENT COEFFICIENT
C
      CALL MAGNUS(BL,DB(NSEG),RES,CGOB,CMPA)
C
C  CALCULATE CMAD. THE ACCELERATION DERIVATIVE CMAD IN THE HYPERSONIC
C  SPEED RANGE IS EQUAL TO ZERO WHEN DETERMINED BY NEWTONIAN THEORY
C
      CMAD=0.0
C
C  CALCULATE SD, DYNAMIC STABILITY FACTOR
C
      AKB=(AIB/(TMASS*DB(NSEG)**2.))**.5
      TKB=(TIB/(TMASS*DB(NSEG)**2.))**.5
      SD=(2.*(CNAT-CDO)+2.*AKB**(-2.)*CMPA)/(CNAT-2.*CDO-TKB**(-2.)*
     1 (CMQT+CMAD))
C
```

```
C  WRITE DYNAMIC STABILITY DATA
C
      WRITE(6,700)
  700 FORMAT(1H ,10X,'***** DYNAMIC STABILITY DATA *****',//)
      WRITE(6,705)ESR,AR
  705 FORMAT(1H ,5X,'EQUIVALENT SAND ROUGHNESS =',E12.6,5X,
     1 'ADMISSIBLE ROUGHNESS =',E12.6)
      WRITE(6,710)RES,U
  710 FORMAT(1H ,5X,'REYNOLDS NUMBER =',E12.6,5X,
     1 'ABSOLUTE VISCOSITY =',E12.6)
      WRITE(6,810)CRE
  810 FORMAT(1H ,5X,'CUTOFF REYNOLDS NUMBER =',E12.6)
      WRITE(6,715)SB,SS
  715 FORMAT(1H ,5X,'BODY MAXIMUM FRONTAL AREA =',F10.5,5X,
     1 'BODY WETTED AREA =',F10.5)
      WRITE(6,720)AKB,TKB
  720 FORMAT(1H ,5X,'DIMENSIONLESS AXIAL RADIUS OF GYRATION =',F10.5,
     1 5X,'DIMENSIONLESS TRANSVERSE RADIUS OF GYRATION =',F10.5,//)
      DO 725 I=1,NSEG
      WRITE(6,800)I
  800 FORMAT(1H ,5X,'PROPERTIES FOR SEGMENT NUMBER ',I5)
      WRITE(6,730)CDP(I),CNQP(I)
  730 FORMAT(1H ,5X,'CDP =',F10.5,5X,'CNQP =',F10.5)
      WRITE(6,735)CMQP(I),CMQ(I)
  735 FORMAT(1H ,5X,'CMQP =',F10.5,5X,'CMQ =',F10.5,//)
  725 CONTINUE
      WRITE(6,740)CF
  740 FORMAT(1H ,5X,'INCOMPRESSIBLE FLAT PLATE SKIN FRICTION ',
     1 'COEFFICIENT (CF) =',F10.5)
      WRITE(6,745)CFCCF
  745 FORMAT(1H ,5X,'COMPRESSIBLE/INCOMPRESSIBLE SKIN FRICTION ',
     1 'COEFFICIENT (CFCCF) =',F10.5)
      WRITE(6,750)CDF
  750 FORMAT(1H ,5X,'BODY SKIN FRICTION DRAG COEFFICIENT (CDF) =',
     1 F10.5)
      WRITE(6,755)CDB
  755 FORMAT(1H ,5X,'BODY BASE DRAG COEFFICIENT (CDB) =',F10.5)
      WRITE(6,760)CDO
  760 FORMAT(1H ,5X,'BODY ZERO LIFT DRAG COEFFICIENT (CDO) =',F10.5)
      WRITE(6,765)CMQT
  765 FORMAT(1H ,5X,'BODY PITCHING DERIVATIVE (CMQT) =',F10.5)
      WRITE(6,780)CMPA
  780 FORMAT(1H ,5X,'DERIVATIVE OF THE MAGNUS MOMENT COEFFICIENT ',
     1 '(CMPA)= ',F10.5)
      WRITE(6,785)CMAD
  785 FORMAT(1H ,5X,'BODY ACCELERATION DERIVATIVE (CMPA) =',F10.5)
      WRITE(6,790)SD
  790 FORMAT(1H ,5X,'DYNAMIC STABILITY FACTOR (SD) =',F10.5)
C
C  CALCULATE STABILITY OF THE BODY
C
      CALL F611 (CMAT,SD,RHO,TIB,AIB,DB(NSEG),VEL,DEN)
      STOP
      END
```

```
C
C*************************************************************
C
      SUBROUTINE IHSS(ISEG,R2,R1,H,DEN,V,AMASS,YB,B,AI,TI)
C
C  CALCULATE THE INERTIA PROPERTIES FOR A HOLLOW SPHERICAL SEGMENT
C
C  ISEG = SEGMENT NUMBER
C  R2 = OUTER RADIUS
C  R1 = INNER RADIUS
C  H = HEIGHT OF SEGMENT
C  DEN = DENSITY OF MATERIAL (MASS/VOLUME)
C  V = VOLUME
C  AMASS = MASS
C  YB = DISTANCE FROM REFERENCE AXIS TO CENTROID
C  B = DISTANCE FROM BASE OF SEGMENT TO CENTROID
C  AI = AXIAL (POLAR) MOMENT OF INERTIA
C  TI = TRANSVERSE MOMENT OF INERTIA
C
      PI=3.1415926
      V=PI*(R2*R1*R1+H*R2*R2-H*R1*R1-R2**3./3.-2.*R1**3./3.)
      YB=3.*((R2*R2-R1*R1)*(4.*H*R2-2.*H*H)-(R2*R2-R1*R1)**2.)
     1 /(4.*((R2*R2-R1*R1)*(3.*H)+3.*R2*R1*R1-R2**3.-2.*R1**3.))
      AMASS=DEN*V
      B=YB-R2+H
      AI=DEN*PI/2.*(8./15.*(R2**5.-R1**5.)+(R2-H)*(R1**4.-R2**4.)
     1 +2./3.*(R2-H)**3.*(R2*R2-R1*R1))
      RR1=R2-R1
      RR2=(R2*R2-R1*R1)
      RR3=(R2**3.-R1**3.)
      RR4=(R2**4.-R1**4.)
      RR5=(R2**5.-R1**5.)
      TI=DEN*PI*(.25*RR4*(R1-R2+H)+RR2*(1./6.*(R1**3.-(R2-H)**3.)
     1 +YB*YB*(R1-R2+H)-YB*(R1*R1-(R2-H)**2.))+.25*R2**4.*RR1
     2 +R2*R2*(1./6.*RR3+YB*YB*RR1-YB*RR2)-3./20.*RR5+.5*YB*RR4
     3 -YB*YB/3.*RR3)
      WRITE(6,300)ISEG
  300 FORMAT(1H ,5X,' PROPERTIES FOR SEGMENT NUMBER ',I5)
      WRITE(6,301)
  301 FORMAT(1H ,10X,'HOLLOW SPHERICAL SEGMENT')
      WRITE(6,302)R2,R1,H
  302 FORMAT(1H ,5X,'OUTER RADIUS = ',F10.5,5X,'INNER RADIUS = ',
     1 F10.5,5X,'HEIGHT = ',F10.5)
      WRITE(6,303)DEN,V,AMASS
  303 FORMAT(1H ,5X,'DENSITY = ',F15.8,5X,'VOLUME = ',F15.8,5X,
     1 'MASS = ',F15.8)
      WRITE(6,304)YB
  304 FORMAT(1H ,5X,'DISTANCE FROM REFERENCE AXIS TO CENTROID = ',
     1 F15.8)
      WRITE(6,305)B
  305 FORMAT(1H ,5X,'DISTANCE FROM BASE OF SEGMENT TO CENTROID = ',
     1 F15.8)
      WRITE(6,306)AI
  306 FORMAT(1H ,5X,'AXIAL MOMENT OF INERTIA = ',F15.8)
```

```
      WRITE(6,307)TI
  307 FORMAT(1H ,5X,'TRANSVERSE MOMENT OF INERTIA = ',F15.8)
      RETURN
      END
C
C***********************************************************
C
      SUBROUTINE IHTC(ISEG,RR2,RR1,R2,R1,H,DEN,V,AMASS,YB,AI,TI)
C
C  CALCULATE THE INERTIA PROPERTIES FOR A HOLLOW TRUNCATED CONE
C
C  ISEG = SEGMENT NUMBER
C  RR2 = OUTER RADIUS AT LARGE END
C  RR1 = INNER RADIUS AT LARGE END
C  R2 = OUTER RADIUS AT SMALL END
C  R1 = INNER RADIUS AT SMALL END
C  H = HEIGHT OF TRUNCATED CONE
C  DEN = DENSITY OF MATERIAL (MASS/VOLUME)
C  V = VOLUME
C  AMASS = MASS
C  YB = DISTANCE FROM CONE BASE TO CENTROID
C  AI = AXIAL(POLAR) MOMENT OF INERTIA
C  TI = TRANSVERSE MOMENT OF INERTIA
C
      PI=3.1415926
      DUMB=(RR2*RR2-RR1*RR1+R2*R2-R1*R1+RR2*R2-RR1*R1)
      V=PI*H/3.*DUMB
      YB=.25*H*(RR2*RR2-RR1*RR1+3.*R2*R2-3.*R1*R1+2.*RR2*R2-
     1 2.*RR1*R1)/DUMB
      AMASS=DEN*V
      AI=DEN*PI*H/10.*((RR2**4.+RR2**3.*R2+RR2*RR2*R2*R2+
     1 RR2*R2**3.+R2**4.)-(RR1**4.+RR1**3.*R1+RR1*RR1*R1*R1+
     2 RR1*R1**3.+R1**4.))
      A1=RR1-R1
      A2=(RR1-R1)**2.
      A3=(RR1-R1)**3.
      A4=(RR1-R1)**4.
      B1=RR2-R2
      B2=(RR2-R2)**2.
      B3=(RR2-R2)**3.
      B4=(RR2-R2)**4.
      TI=(.75*AMASS*(RR2**4.-2.*RR2**3.*B1+2.*RR2**2.*B2-RR2*B3
     1 +B4/5.-RR1**4.+2.*RR1**3.*A1-2.*RR1**2.*A2+RR1*A3-A4/5.)
     2 +3.*AMASS*(H*H*(RR2*RR2/3.+B2/5.-RR2*B1/2.-RR1*RR1/3.
     3 -A2/5.+RR1*A1/2.)+YB*YB*(RR2*RR2+B2/3.-RR2*B1-RR1*RR1
     4 -A2/3.+RR1*A1)+YB*H*(-RR2*RR2-B2/2.+4.*RR2*B1/3.
     5 +RR1*RR1+A2/2.-4.*RR1*A1/3.)))/DUMB
      WRITE(6,310)ISEG
  310 FORMAT(1H ,5X,' PROPERTIES FOR SEGMENT NUMBER ',I5)
      WRITE(6,311)
  311 FORMAT(1H ,10X,'HOLLOW TRUNCATED CONE')
      WRITE(6,312)RR2,RR1
  312 FORMAT(1H ,5X,'OUTER RADIUS AT LARGE END = ',F10.5,5X,
     1 'INNER RADIUS AT LARGE END = ',F10.5)
```

```
      WRITE(6,313)R2,R1
  313 FORMAT(1H ,5X,'OUTER RADIUS AT SMALL END = ',F10.5,5X,
     1 'INNER RADIUS AT SMALL END = ',F10.5)
      WRITE(6,314)H
  314 FORMAT(1H ,5X,'HEIGHT = ',F10.5)
      WRITE(6,315)DEN,V,AMASS
  315 FORMAT(1H ,5X,'DENSITY = ',F15.8,5X,'VOLUME = ',F15.8,5X,
     1 'MASS = ',F15.8)
      WRITE(6,316)YB
  316 FORMAT(1H ,5X,'DISTANCE FROM CONE BASE TO CENTROID = ',F15.8)
      WRITE(6,317)AI
  317 FORMAT(1H ,5X,'AXIAL MOMENT OF INERTIA = ',F15.8)
      WRITE(6,318)TI
  318 FORMAT(1H ,5X,'TRANSVERSE MOMENT OF INERTIA = ',F15.8)
      RETURN
      END
C
C***********************************************************
C
C***********************************************************
C
      SUBROUTINE COEFF1
C
C  GENERATES CUBIC SPLINE COEFFICIENTS FOR FIG. 4.2.1.1-23
C  NORMAL-FORCE-CURVE SLOPE FOR SPHERICAL SEGMENTS
C
      COMMON/XY1/X1(11),Y1(11)
      COMMON/BCD1/B1(11),C1(11),D1(11)
      DATA(X1(I),I=1,11)/0.0000,0.1000,0.2000,0.3000,0.4000,
     1                   0.5000,0.6000,0.7000,0.8000,0.9000,
     2                   1.0000/
      DATA(Y1(I),I=1,11)/0.0000,0.1748,0.3497,0.5070,0.6399,
     1                   0.7517,0.8392,0.9091,0.9580,0.9895,
     2                   1.0000/
      N=11
      CALL SPLINE(N,X1,Y1,B1,C1,D1)
      RETURN
      END
C
C***********************************************************
C
      SUBROUTINE COEFF2
C
C  GENERATES CUBIC SPLINE COEFFICIENTS FOR FIG. 4.2.1.1-26
C  NORMAL-FORCE-CURVE SLOPE FOR CONE FRUSTRUMS
C
      COMMON/XY2/X2(11,10),Y2(11,10)
      COMMON/BCD2/B2(11,10),C2(11,10),D2(11,10)
      DIMENSION B(10),C(10),D(10),XXX(10),YYY(10)
      DATA(X2(1,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
     1                      50.000,60.000,70.000,80.000,90.000/
      DATA(Y2(1,I),I=1,10)/2.0000,1.9406,1.7727,1.5140,1.1818,
     1                      0.8287,0.5035,0.2448,0.0664,0.0000/
      DATA(X2(2,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
```

```
     1                       50.000,60.000,70.000,80.000,90.000/
      DATA(Y2(2,I),I=1,10)/1.9825,1.9161,1.7448,1.4790,1.1678,
     1                       0.6287,0.5035,0.2448,0.0664,0.0000/
      DATA(X2(3,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
     1                       50.000,60.000,70.000,80.000,90.000/
      DATA(Y2(3,I),I=1,10)/1.9196,1.8601,1.6853,1.4371,1.1224,
     1                       0.7867,0.4755,0.2448,0.0664,0.0000/
      DATA(X2(4,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
     1                       50.000,60.000,70.000,80.000,90.000/
      DATA(Y2(4,I),I=1,10)/1.8217,1.7622,1.6119,1.3601,1.0664,
     1                       0.7517,0.4510,0.2203,0.0629,0.0000/
      DATA(X2(5,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
     1                       50.000,60.000,70.000,80.000,90.000/
      DATA(Y2(5,I),I=1,10)/1.6853,1.6329,1.4755,1.2587,0.9825,
     1                       0.6923,0.4231,0.1958,0.0594,0.0000/
      DATA(X2(6,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
     1                       50.000,60.000,70.000,80.000,90.000/
      DATA(Y2(6,I),I=1,10)/1.5070,1.4510,1.3217,1.1259,0.8811,
     1                       0.6259,0.3706,0.1783,0.0559,0.0000/
      DATA(X2(7,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
     1                       50.000,60.000,70.000,80.000,90.000/
      DATA(Y2(7,I),I=1,10)/1.2867,1.2413,1.1259,0.9580,0.7552,
     1                       0.5315,0.3252,0.1538,0.0455,0.0000/
      DATA(X2(8,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
     1                       50.000,60.000,70.000,80.000,90.000/
      DATA(Y2(8,I),I=1,10)/1.0210,0.9895,0.8986,0.7622,0.5909,
     1                       0.4161,0.2552,0.1224,0.0315,0.0000/
      DATA(X2(9,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
     1                       50.000,60.000,70.000,80.000,90.000/
      DATA(Y2(9,I),I=1,10)/0.7168,0.6923,0.6224,0.5350,0.4196,
     1                       0.2937,0.1748,0.0804,0.0210,0.0000/
      DATA(X2(10,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
     1                        50.000,60.000,70.000,80.000,90.000/
      DATA(Y2(10,I),I=1,10)/0.3671,0.3566,0.3287,0.2797,0.2203,
     1                        0.1503,0.0909,0.0420,0.0105,0.0000/
      DATA(X2(11,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
     1                        50.000,60.000,70.000,80.000,90.000/
      DATA(Y2(11,I),I=1,10)/0.0000,0.0000,0.0000,0.0000,0.0000,
     1                        0.0000,0.0000,0.0000,0.0000,0.0000/
      N=10
      DO 200 J=1,11
      DO 210 K=1,10
      XXX(K)=X2(J,K)
      YYY(K)=Y2(J,K)
  210 CONTINUE
      CALL SPLINE(N,XXX,YYY,B,C,D)
      DO 220 K=1,10
      B2(J,K)=B(K)
      C2(J,K)=C(K)
      D2(J,K)=D(K)
  220 CONTINUE
  200 CONTINUE
      RETURN
      END
```

```
C
C*************************************************************
C
      SUBROUTINE COEFF3
C
C  GENERATES CUBIC SPLINE COEFFICIENTS FOR FIG. 4.2.2.1-25A
C  CMAP FOR CONE FRUSTRUMS
C
      COMMON/XY3/X3(11,10),Y3(11,10)
      COMMON/XYB/XXB(6),YYB(6)
      COMMON/BCD3/B3(11,10),C3(11,10),D3(11,10)
      COMMON/BCD3B/B3B(6),C3B(6),D3B(6)
      DIMENSION B(10),C(10),D(10),XXX(10),YYY(10)
      DATA(X3(1,I),I=1,10)/15.279,20.000,25.000,30.000,40.000,
     1                     50.000,60.000,70.000,80.000,90.000/
      DATA(Y3(1,I),I=1,10)/-2.400,-1.800,-1.398,-1.149,-0.796,
     1                     -0.564,-0.388,-0.249,-0.125,0.0000/
      DATA(X3(2,I),I=1,10)/13.219,15.000,20.000,25.000,30.000,
     1                     40.000,50.000,60.000,75.000,90.000/
      DATA(Y3(2,I),I=1,10)/-2.400,-2.114,-1.599,-1.249,-1.017,
     1                     -0.723,-0.526,-0.367,-0.183,0.0000/
      DATA(X3(3,I),I=1,10)/11.159,15.000,20.000,25.000,30.000,
     1                     40.000,50.000,60.000,75.000,90.000/
      DATA(Y3(3,I),I=1,10)/-2.400,-1.807,-1.353,-1.083,-0.900,
     1                     -0.658,-0.485,-0.350,-0.183,0.0000/
      DATA(X3(4,I),I=1,10)/9.0990,10.000,15.000,20.000,25.000,
     1                     35.000,45.000,60.000,75.000,90.000/
      DATA(Y3(4,I),I=1,10)/-2.400,-2.118,-1.453,-1.100,-0.903,
     1                     -0.661,-0.516,-0.339,-0.170,0.0000/
      DATA(X3(5,I),I=1,10)/6.8670,10.000,15.000,20.000,25.000,
     1                     35.000,45.000,60.000,75.000,90.000/
      DATA(Y3(5,I),I=1,10)/-2.400,-1.668,-1.159,-0.893,-0.737,
     1                     -0.564,-0.460,-0.315,-0.159,0.0000/
      DATA(X3(6,I),I=1,10)/5.0000,10.000,15.000,20.000,25.000,
     1                     35.000,45.000,60.000,75.000,90.000/
      DATA(Y3(6,I),I=1,10)/-2.400,-1.239,-0.862,-0.685,-0.588,
     1                     -0.471,-0.398,-0.287,-0.149,0.0000/
      DATA(X3(7,I),I=1,10)/5.0000,10.000,15.000,20.000,30.000,
     1                     40.000,50.000,60.000,75.000,90.000/
      DATA(Y3(7,I),I=1,10)/-1.595,-0.845,-0.613,-0.498,-0.402,
     1                     -0.350,-0.308,-0.246,-0.138,0.0000/
      DATA(X3(8,I),I=1,10)/5.0000,10.000,15.000,20.000,30.000,
     1                     40.000,50.000,60.000,75.000,90.000/
      DATA(Y3(8,I),I=1,10)/-0.900,-0.519,-0.395,-0.339,-0.298,
     1                     -0.284,-0.249,-0.204,-0.114,0.0000/
      DATA(X3(9,I),I=1,10)/5.0000,10.000,15.000,25.000,35.000,
     1                     45.000,55.000,65.000,75.000,90.000/
      DATA(Y3(9,I),I=1,10)/-0.436,-0.260,-0.218,-0.194,-0.190,
     1                     -0.180,-0.163,-0.128,-0.083,0.0000/
      DATA(X3(10,I),I=1,10)/5.0000,10.000,15.000,20.000,30.000,
     1                      40.000,50.000,60.000,75.000,90.000/
      DATA(Y3(10,I),I=1,10)/-0.118,-0.090,-0.080,-0.083,-0.097,
     1                      -0.100,-0.093,-0.080,-0.055,0.0000/
      DATA(X3(11,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
```

```
     1                      50.000,60.000,70.000,80.000,90.000/
      DATA(Y3(11,I),I=1,10)/0.0000,0.0000,0.0000,0.0000,0.0000,
     1                      0.0000,0.0000,0.0000,0.0000,0.0000/
      DATA(XXB(I),I=1,6)/5.0000,6.8670,9.0990,11.159,13.219,15.279/
      DATA(YYB(I),I=1,6)/0.5000,0.4000,0.3000,0.2000,0.1000,0.0000/
      N=10
      DO 200 J=1,11
      DO 210 K=1,10
      XXX(K)=X3(J,K)
      YYY(K)=Y3(J,K)
  210 CONTINUE
      CALL SPLINE(N,XXX,YYY,B,C,D)
      DO 220 K=1,10
      B3(J,K)=B(K)
      C3(J,K)=C(K)
      D3(J,K)=D(K)
  220 CONTINUE
  200 CONTINUE
C
C GENERATE THE CUBIC SPLINE COEFFICIENTS FOR THE BOTTOM OF THE
C GRAPH WHERE CMAP = -2.4 AND A/D IS .5 TO 0
C
      N=6
      CALL SPLINE(N,XXB,YYB,B3B,C3B,D3B)
      RETURN
      END
C
C**************************************************************
C
      SUBROUTINE COEFF4
C
C  GENERATES CUBIC SPLINE COEFFICIENTS FOR FIG. 4.2.2.1-25B
C  CMAP FOR SPHERICAL SEGMENTS
C
      COMMON/XY4/X4(13),Y4(13)
      COMMON/BCD4/B4(13),C4(13),D4(13)
      DATA(X4(I),I=1,13)/0.0000,0.0250,0.0500,0.1000,0.2000,
     1                   0.3000,0.4000,0.5000,0.6000,0.7000,
     2                   0.8000,0.9000,1.0000/
      DATA(Y4(I),I=1,13)/0.0000,-.0918,-.1482,-.2188,-.3000,
     1                   -.3600,-.3988,-.4341,-.4588,-.4800,
     2                   -.4941,-.5012,-.5012/
      N=13
      CALL SPLINE(N,X4,Y4,B4,C4,D4)
      RETURN
      END
C
C**************************************************************
C
      SUBROUTINE F421123(BLUNT,CNAP)
C
C  CALCULATES CNAP FOR A GIVEN NOSE BLUNTNESS
C  NORMAL-FORCE-CURVE SLOPE FOR SPHERICAL SEGMENTS
C
```

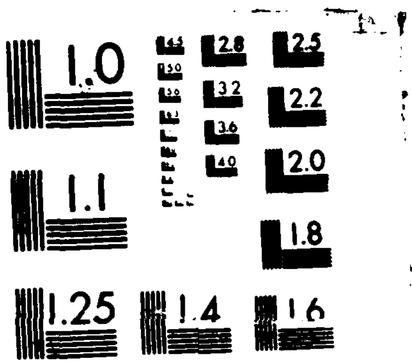
```
      COMMON/XY1/X1(11),Y1(11)
      COMMON/BCD1/B1(11),C1(11),D1(11)
      N=11
      CALL SEVAL(BLUNT,CNAP,D1Y0,D2Y0,D3Y0,X1,Y1,B1,C1,D1,N)
      RETURN
      END
C
C*********************************************************
C
      SUBROUTINE F421126(THETA,CNAP,AD)
C
C  CALCULATES CNAP FOR A GIVEN SEMICONE ANGLE
C  NORMAL-FORCE-CURVE SLOPE FOR CONE FRUSTRUMS
C
      COMMON/XY2/X2(11,10),Y2(11,10)
      COMMON/BCD2/B2(11,10),C2(11,10),D2(11,10)
      DIMENSION CNA(11),XXX(10),YYY(10),B(10),C(10),D(10)
      DIMENSION XX(11),BB(11),CC(11),DD(11)
      DATA(XX(I),I=1,11)/0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,
     1                   0.9,1.0/
      DO 200 J=1,11
      DO 210 K=1,10
      XXX(K)=X2(J,K)
      YYY(K)=Y2(J,K)
  210 CONTINUE
      DO 220 K=1,10
      B(K)=B2(J,K)
      C(K)=C2(J,K)
      D(K)=D2(J,K)
  220 CONTINUE
      CALL SEVAL(THETA,DUMB,D1Y0,D2Y0,D3Y0,XXX,YYY,B,C,D,10)
      CNA(J)=DUMB
  200 CONTINUE
      CALL SPLINE(11,XX,CNA,BB,CC,DD)
      CALL SEVAL(AD,CNAP,D1Y0,D2Y0,D3Y0,XX,CNA,BB,CC,DD,11)
      RETURN
      END
C
C*********************************************************
C
      SUBROUTINE F422125A(THETA,CMAP,AD)
C
C  CALCULATES CMAP FOR A GIVEN SEMICONE ANGLE
C  CMAP FOR CONE FRUSTRUMS
C
      COMMON/XY3/X3(11,10),Y3(11,10)
      COMMON/XYB/XXB(6),YYB(6)
      COMMON/BCD3/B3(11,10),C3(11,10),D3(11,10)
      COMMON/BCD3B/B3B(6),C3B(6),D3B(6)
      DIMENSION XX1(11),XX2(11),XX3(10),XX4(9),XX5(8),XX6(7)
      DIMENSION XXX(10),YYY(10),B(10),C(10),D(10)
      DIMENSION CMA1(11),BB1(11),CC1(11),DD1(11)
      DIMENSION CMA2(11),BB2(11),CC2(11),DD2(11)
      DIMENSION CMA3(10),BB3(10),CC3(10),DD3(10)
```

```
      DIMENSION CMA4(9),BB4(9),CC4(9),DD4(9)
      DIMENSION CMA5(8),BB5(8),CC5(8),DD5(8)
      DIMENSION CMA6(7),BB6(7),CC6(7),DD6(7)
      DATA(XX1(I),I=1,11)/0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,
     1                    0.9,1.0/
C
C  REGION 1 ( THETA .GE. 15.279)
C
      IF(THETA.LT.15.279)GO TO 10
      DO 200 J=1,11
      DO 210 K=1,10
      XXX(K)=X3(J,K)
      YYY(K)=Y3(J,K)
  210 CONTINUE
      DO 220 K=1,10
      B(K)=B3(J,K)
      C(K)=C3(J,K)
      D(K)=D3(J,K)
  220 CONTINUE
      CALL SEVAL(THETA,DUMB,D1Y0,D2Y0,D3Y0,XXX,YYY,B,C,D,10)
      CMA1(J)=DUMB
  200 CONTINUE
      CALL SPLINE(11,XX1,CMA1,BB1,CC1,DD1)
      CALL SEVAL(AD,CMAP,D1Y0,D2Y0,D3Y0,XX1,CMA1,BB1,CC1,DD1,11)
      GO TO 1000
C
C  REGION 2 ( THETA .LT. 15.279 BUT .GE. 13.219)
C
   10 IF(THETA.LT.13.219)GO TO 20
      DO 201 J=2,11
      DO 211 K=1,10
      XXX(K)=X3(J,K)
      YYY(K)=Y3(J,K)
  211 CONTINUE
      DO 221 K=1,10
      B(K)=B3(J,K)
      C(K)=C3(J,K)
      D(K)=D3(J,K)
  221 CONTINUE
      CALL SEVAL(THETA,DUMB,D1Y0,D2Y0,D3Y0,XXX,YYY,B,C,D,10)
      CMA2(J)=DUMB
      XX2(J)=XX1(J)
  201 CONTINUE
      CALL SEVAL(THETA,DUMB,D1Y0,D2Y0,D3Y0,XXB,YYB,B3B,C3B,D3B,6)
      CMA2(1)=-2.4
      XX2(1)=DUMB
      IF(AD.LT.DUMB)GO TO 2000
      CALL SPLINE(11,XX2,CMA2,BB2,CC2,DD2)
      CALL SEVAL(AD,CMAP,D1Y0,D2Y0,D3Y0,XX2,CMA2,BB2,CC2,DD2,11)
      GO TO 1000
C
C  REGION 3 ( THETA .LT. 13.219 BUT .GE. 11.159)
C
   20 IF(THETA.LT.11.159)GO TO 30
```

```
      DO 202 J=3,11
      DO 212 K=1,10
      XXX(K)=X3(J,K)
      YYY(K)=Y3(J,K)
  212 CONTINUE
      DO 222 K=1,10
      B(K)=B3(J,K)
      C(K)=C3(J,K)
      D(K)=D3(J,K)
  222 CONTINUE
      CALL SEVAL(THETA,DUMB,D1Y0,D2Y0,D3Y0,XXX,YYY,B,C,D,10)
      CMA3(J-1)=DUMB
      XX3(J-1)=XX1(J)
  202 CONTINUE
      CALL SEVAL(THETA,DUMB,D1Y0,D2Y0,D3Y0,XXB,YYB,B3B,C3B,D3B,6)
      CMA3(1)=-2.4
      XX3(1)=DUMB
      IF(AD.LT.DUMB)GO TO 2000
      CALL SPLINE(10,XX3,CMA3,BB3,CC3,DD3)
      CALL SEVAL(AD,CMAP,D1Y0,D2Y0,D3Y0,XX3,CMA3,BB3,CC3,DD3,10)
      GO TO 1000
C
C  REGION 4 ( THETA .LT. 11.159 BUT .GE. 9.099)
C
   30 IF(THETA.LT.9.099)GO TO 40
      DO 203 J=4,11
      DO 213 K=1,10
      XXX(K)=X3(J,K)
      YYY(K)=Y3(J,K)
  213 CONTINUE
      DO 223 K=1,10
      B(K)=B3(J,K)
      C(K)=C3(J,K)
      D(K)=D3(J,K)
  223 CONTINUE
      CALL SEVAL(THETA,DUMB,D1Y0,D2Y0,D3Y0,XXX,YYY,B,C,D,10)
      CMA4(J-2)=DUMB
      XX4(J-2)=XX1(J)
  203 CONTINUE
      CALL SEVAL(THETA,DUMB,D1Y0,D2Y0,D3Y0,XXB,YYB,B3B,C3B,D3B,6)
      CMA4(1)=-2.4
      XX4(1)=DUMB
      IF(AD.LT.DUMB)GO TO 2000
      CALL SPLINE(9,XX4,CMA4,BB4,CC4,DD4)
      CALL SEVAL(AD,CMAP,D1Y0,D2Y0,D3Y0,XX4,CMA4,BB4,CC4,DD4,9)
      GO TO 1000
C
C  REGION 5 ( THETA .LT. 9.099 BUT .GE. 6.867)
C
   40 IF(THETA.LT.6.867)GO TO 50
      DO 204 J=5,11
      DO 214 K=1,10
      XXX(K)=X3(J,K)
      YYY(K)=Y3(J,K)
```

```
  214 CONTINUE
      DO 224 K=1,10
      B(K)=B3(J,K)
      C(K)=C3(J,K)
      D(K)=D3(J,K)
  224 CONTINUE
      CALL SEVAL(THETA,DUMB,D1Y0,D2Y0,D3Y0,XXX,YYY,B,C,D,10)
      CMA5(J-3)=DUMB
      XX5(J-3)=XX1(J)
  204 CONTINUE
      CALL SEVAL(THETA,DUMB,D1Y0,D2Y0,D3Y0,XXB,YYB,B3B,C3B,D3B,6)
      CMA5(1)=-2.4
      XX5(1)=DUMB
      IF(AD.LT.DUMB)GO TO 2000
      CALL SPLINE(8,XX5,CMA5,BB5,CC5,DD5)
      CALL SEVAL(AD,CMAP,D1Y0,D2Y0,D3Y0,XX5,CMA5,BB5,CC5,DD5,8)
      GO TO 1000
C
C  REGION 6 (THETA .LT. 6.867 BUT .GE. 5.000)
C
   50 IF(THETA.LT.5.000)GO TO 60
      DO 205 J=6,11
      DO 215 K=1,10
      XXX(K)=X3(J,K)
      YYY(K)=Y3(J,K)
  215 CONTINUE
      DO 225 K=1,10
      B(K)=B3(J,K)
      C(K)=C3(J,K)
      D(K)=D3(J,K)
  225 CONTINUE
      CALL SEVAL(THETA,DUMB,D1Y0,D2Y0,D3Y0,XXX,YYY,B,C,D,10)
      CMA6(J-4)=DUMB
      XX6(J-4)=XX1(J)
  205 CONTINUE
      CALL SEVAL(THETA,DUMB,D1Y0,D2Y0,D3Y0,XXB,YYB,B3B,C3B,D3B,6)
      CMA6(1)=-2.4
      XX6(1)=DUMB
      IF(AD.LT.DUMB)GO TO 2000
      CALL SPLINE(7,XX6,CMA6,BB6,CC6,DD6)
      CALL SEVAL(AD,CMAP,D1Y0,D2Y0,D3Y0,XX6,CMA6,BB6,CC6,DD6,7)
      GO TO 1000
   60 CMAP=0.0
      WRITE(6,4000)THETA
 4000 FORMAT(1H ,5X,'THETA = ',F10.5,5X,'OUT OF THETA RANGE')
      GO TO 1000
 2000 WRITE(6,3000)AD,THETA
 3000 FORMAT(1H ,5X,'A/D = ',F10.5,5X,'WHICH IS OUT OF RANGE
     1 ' FOR THETA = ',F10.5)
      CMAP=999.99
 1000 RETURN
      END
C
C*****************************************************************...........
```

AD-A179 857 SFFSTAB: A COMPUTER PROGRAM TO CALCULATE THE AERODYNAMIC 2/2
STABILITY OF A SE (U) DEFENCE RESEARCH ESTABLISHMENT
SUFFIELD RALSTON (ALBERTA) C A WEICKERT MAR 87
UNCLASSIFIED DRES-SM-1194 F/G 19/10 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

```
C
      SUBROUTINE F422125B(BLUNT,CMAP)
C
C  CALCULATES CMAP FOR A GIVEN NOSE BLUNTNESS
C  CMAP FOR SPHERICAL SEGMENTS
C
      COMMON/XY4/X4(13),Y4(13)
      COMMON/BCD4/B4(13),C4(13),D4(13)
      N=13
      CALL SEVAL(BLUNT,CMAP,D1Y0,D2Y0,D3Y0,X4,Y4,B4,C4,D4,N)
      RETURN
      END
C
C
C***********************************************************
C
      SUBROUTINE F423166(BLUNT,CDP)
C
C  CALCULATE CDP, NEWTONIAN DRAG COEFFICIENT FOR SPHERICAL
C  SEGMENTS REFERRED TO BASE AREA OF SEGMENT
C
      CDP=BLUNT**2.-2.*BLUNT+2.
      RETURN
      END
C
C***********************************************************
C
      SUBROUTINE F721213B(CMQP)
C
C  CALCULATE CMQP, PITCHING DERIVATIVE FOR SPHERICAL SEGMENTS
C  BASED ON THE BASE AREA AND THE SQUARE OF THE BASE DIAMETER
C
      CMQP=-.5
      RETURN
      END
C
C***********************************************************
C
      SUBROUTINE F721212(THETA,AD,CMQP)
C
C  CALCULATE THE PITCHING DERIVATIVE CMQP DUE TO INCLINED SIDES
C  OF CONE FRUSTRUMS
C
      PI=3.1415926
      RAD=THETA*PI/180.
      A=6.*AD*AD*(1.-AD*AD)
      B=-8.*AD*(1.-AD**3.)
      C=3.*(1.-AD**4.)
      CMQP=-1./(6.*(SIN(RAD))**2.)*(A*(COS(RAD))**4.+B*(COS(RAD))**2.
     1 +C)
      IF(THETA.GE.5.0)GO TO 100
      CMQP=0.0
      WRITE(6,105)
  105 FORMAT(1H ,5X,'OUT OF THETA RANGE')
```

```
  100 IF(CMQP.GE.-4.8)GO TO 200
      WRITE(6,110)
  110 FORMAT(1H ,5X,'OUT OF CMQP RANGE')
  200 RETURN
      END
C
C***********************************************************
C
      SUBROUTINE F721213A(THETA,AD,CMQP)
C
C  CALCULATE THE PITCHING DERIVATIVE CMQP FOR THE TOTAL CONE FRUSTRUM
C
      CALL F721212(THETA,AD,CMQP)
      IF(CMQP.EQ.0.0)GO TO 100
      CMQP=CMQP-(AD**4.)/2.
  100 RETURN
      END
C
C***********************************************************
C
      SUBROUTINE F423167S(THETA,AD,CDP)
C
C  CALCULATE CDP, DRAG-FORCE COEFFICIENT DUE ONLY TO THE INCLINED
C  SIDES OF A CONE FRUSTRUM, BASED ON BODY BASE AREA
C
      PI=3.1415926
      RAD=THETA*PI/180.
      CDP=2.*(SIN(RAD))**2.*(1.-AD*AD)
      RETURN
      END
C
C***********************************************************
C
      SUBROUTINE F423167T(THETA,AD,CDP)
C
C  CALCULATE CDP, DRAG-FORCE COEFFICIENT FOR THE TOTAL CONE FRUSTRUM
C
      PI=3.1415926
      RAD=THETA*PI/180.
      CDP=2.*((SIN(RAD))**2.*(1.-AD*AD)+AD*AD)
      RETURN
      END
C
C***********************************************************
C
      SUBROUTINE COEFF5
C
C  GENERATES CUBIC SPLINE COEFFICIENTS FOR FIG. 4.2.3.1.-68
C  COMPRESSIBILITY EFFECT ON TURBULENT SKIN FRICTION
C
      COMMON/XY5/X5(8),Y5(8)
      COMMON/BCD5/B5(8),C5(8),D5(8)
      DATA(X5(I),I=1,8)/0.0000,1.0000,2.0000,3.0000,
     1                 4.0000,5.0000,6.0000,10.000/
```

```
      DATA(Y5(I),I=1,8)/1.0000,0.9271,0.7708,0.6146,
     1                 0.5000,0.3958,0.3333,0.1289/
      CALL SPLINE(8,X5,Y5,B5,C5,D5)
      RETURN
      END
C
C***********************************************************
C
      SUBROUTINE F423168(VEL,CFCCF)
C
C  CALCULATES CFC/CF, COMPRESSIBILITY EFFECT ON TURBULENT
C  SKIN FRICTION
C
      COMMON/XY5/X5(8),Y5(8)
      COMMON/BCD5/B5(8),C5(8),D5(8)
C
C  VEL = PROJECTILE VELOCITY(IN/SEC)
C  A = SPEED OF SOUND IN AIR(1116.4 FT/SEC)
C  AMACH = PROJECTILE VELOCITY (MACH NUMBER)
C
      A=1116.4
      AMACH=VEL/(12.*A)
      IF(AMACH.GT.10.)GO TO 100
      CALL SEVAL(AMACH,CFCCF,D1Y0,D2Y0,D3Y0,X5,Y5,B5,C5,D5,8)
      GO TO 200
  100 WRITE(6,300)AMACH
  300 FORMAT(1H ,10X,'MACH NUMBER =',F10.5,5X,'WHICH IS OUT OF RANGE')
  200 RETURN
      END
C
C***********************************************************
C
      SUBROUTINE COEFF6
C
C  GENERATES CUBIC SPLINE COEFFICIENTS FOR FIG. 4.1.5.1-27
C  CUTOFF REYNOLDS NUMBER
C
      COMMON/XY6/X6(5),Y6(5)
      COMMON/BCD6/B6(5),C6(5),D6(5)
      DATA(X6(I),I=1,5)/1.80E03,1.65E04,1.47E05,1.30E06,1.00E07/
      DATA(Y6(I),I=1,5)/1.00E05,1.00E06,1.00E07,1.00E08,8.50E08/
      CALL SPLINE(5,X6,Y6,B6,C6,D6)
      RETURN
      END
C
C***********************************************************
C
      SUBROUTINE F415127(AR,CRE)
C
C  CALCULATES CUTOFF REYNOLDS NUMBER
C
      COMMON/XY6/X6(5),Y6(5)
      COMMON/BCD6/B6(5),C6(5),D6(5)
C
```

```
C  AR = ADMISSIBLE ROUGHNESS
C  CRE = CUTOFF REYNOLDS NUMBER
C
      CALL SEVAL(AR,CRE,D1Y0,D2Y0,D3Y0,X6,Y6,B6,C6,D6,5)
      RETURN
      END
C
C*************************************************************
C
       SUBROUTINE COEFF7
C
C  GENERATES CUBIC SPLINE COEFFICIENTS FOR FIG. 4.1.5.1-26
C  TURBULENT MEAN SKIN FRICTION COEFFICIENT ON AN INSULATED
C  FLAT PLATE
C
      COMMON/XY7/X7(26),Y7(26)
      COMMON/BCD7/B7(26),C7(26),D7(26)
      DATA(X7(I),I=1,26)/3.3E05,5.0E05,7.0E05,9.0E05,1.0E06,
     1                   1.5E06,2.0E06,3.0E06,5.0E06,7.0E06,
     2                   9.0E06,1.0E07,1.5E07,2.0E07,3.0E07,
     3                   5.0E07,7.0E07,9.0E07,1.0E08,1.5E08,
     4                   2.0E08,3.0E08,5.0E08,7.0E08,9.0E08,
     5                   1.0E09/
      DATA(Y7(I),I=1,26)/.00550,.00505,.00474,.00454,.00445,
     1                   .00415,.00395,.00369,.00338,.00320,
     2                   .00306,.00300,.00283,.00270,.00254,
     3                   .00235,.00223,.00215,.00212,.00199,
     4                   .00191,.00182,.00170,.00164,.00160,
     5                   .00158/
      CALL SPLINE(26,X7,Y7,B7,C7,D7)
      RETURN
      END
C
C*************************************************************
C
      SUBROUTINE F415126(RE,CF)
C
C  CALCULATE TURBULENT MEAN SKIN FRICTION COEFFICIENT ON AN
C  INSULATED FLAT PLATE
C
      COMMON/XY7/X7(26),Y7(26)
      COMMON/BCD7/B7(26),C7(26),D7(26)
C
C  RE = REYNOLDS NUMBER
C  CF = SKIN FRICTION COEFFICIENT
C
      CALL SEVAL(RE,CF,D1Y0,D2Y0,D3Y0,X7,Y7,B7,C7,D7,26)
      RETURN
      END
C
C*************************************************************
C
      SUBROUTINE COEFF8
C
```

```
C  GENERATES CUBIC SPLINE COEFFICIENTS FOR FIG. 4.2.3.1-60
C  BASE DRAG COEFFICIENT WITH NO BOATTAIL
C
      COMMON/XY8/X8(8),Y8(8)
      COMMON/BCD8/B8(8),C8(8),D8(8)
      DATA(X8(I),I=1,8)/1.5000,2.0000,2.5000,3.5000,
     1                  4.5000,6.0000,7.0000,10.000/
      DATA(Y8(I),I=1,8)/0.1776,0.1440,0.1168,0.0800,
     1                  0.0560,0.0352,0.0272,0.0110/
      CALL SPLINE(8,X8,Y8,B8,C8,D8)
      RETURN
      END
C
C************************************************************
C
      SUBROUTINE F423160(VEL,CDB)
C
C  CALCULATES CDB, BASE DRAG COEFFICIENT(WITH NO BOATTAIL)
C
      COMMON /XY8/X8(8),Y8(8)
      COMMON /BCD8/B8(8),C8(8),D8(8)
C
C  VEL = PROJECTILE VELOCITY (IN/SEC)
C  A = SPEED OF SOUND IN AIR (1116.4 FT/SEC)
C  AMACH = PROJECTILE VELOCITY (MACH NUMBER)
C  CDB = BASE DRAG COEFFICIENT
C
      A=1116.4
      AMACH=VEL/(12.*A)
      CALL SEVAL(AMACH,CDB,D1Y0,D2Y0,D3Y0,X8,Y8,B8,C8,D8,8)
      RETURN
      END
C
C************************************************************
C
      SUBROUTINE F72119A(THETA,AD,CNQP)
C
C  CALCULATE CNQP, PITCHING DERIVATIVE FOR CONE FRUSTRUMS
C
      PI=3.1415926
      RAD=THETA*PI/180.
      CNQP=2./(3.*TAN(RAD))*(2.*(1-AD**3.)-3.*AD*(COS(RAD)**2.)
     1 *(1-AD*AD))
      IF(THETA.GE.5.0)GO TO 100
      CNQP=0.0
      WRITE(6,105)
  105 FORMAT(1H ,5X,'OUT OF THETA RANGE')
  100 IF(CNQP.LE.4.4)GO TO 200
      WRITE(6,110)
  110 FORMAT(1H ,5X,'OUT OF CNQP RANGE')
  200 RETURN
      END
C
C************************************************************
```

```
C
      SUBROUTINE F72119B(BLUNT,CNQP)
C
C  CALCULATE CNQP, PITCHING DERIVATIVE FOR SPHERICAL SEGMENTS
C
      CNQP=(BLUNT*(2.-BLUNT))**.5
      RETURN
      END
C
C***********************************************************
C
      SUBROUTINE MAGNUS(BL,DB,RES,CGOB,CMPA)
C
C  CALCULATE THE DERIVATIVE OF THE MAGNUS MOMENT COEFFICIENT
C
      DMCP=ABS(CGOB-.333*BL)
      CMPA=26.3*(BL/DB)**2.*DMCP/(RES**.5)
      RETURN
      END
C
C
C***********************************************************
C
      SUBROUTINE F611 (CMAT,SD,RHO,TIB,AIB,DB,VEL,DEN)
C
C  SUBROUTINE TO DETERMINE BODY STABILITY
C
      DIMENSION TLS(25),HLS(25),RCS(25),AMASSL(25)
      PI=3.1415926
      IF(SD.LT.0.0.OR.SD.GT.2.0)GO TO 10
      IF(CMAT.GT.0.0)GO TO 20
      WRITE(6,25)CMAT
   25 FORMAT(1H ,5X,'CMA =',F10.5,5X,'(NEGATIVE)')
      WRITE(6,30)SD
   30 FORMAT(1H ,5X,'SD =',F10.5,5X,'(IN THE RANGE 0-2)')
      WRITE(6,35)
   35 FORMAT(1H ,5X,'BODY IS DYNAMICALLY STABLE AT ANY SPIN RATE')
      GO TO 500
   20 SGI=SD*(2.-SD)
      SG=1./SGI
      W=(SG*PI*RHO*TIB*CMAT*DB**3./(2.*AIB**2.))**.5*VEL
      RPM=W*30./PI
      WRITE(6,40)CMAT
   40 FORMAT(1H ,5X,'CMA =',F10.5,5X,'(POSITIVE)')
      WRITE(6,30)SD
      WRITE(6,65)SGI,SG
   65 FORMAT(1H ,5X,'SGI =',F10.5,5X,'SG =',F10.5,5X,'(VALUES ON ',
     1 'DYNAMIC STABLE/UNSTABLE CURVE)')
      WRITE(6,45)W,RPM
   45 FORMAT(1H ,5X,'BODY IS DYNAMICALLY STABLE AT SPIN RATES ',
     1 'GREATER THAN ',E12.6,3X,'(RAD/SEC)',5X,E12.6,3X,'(RPM)')
C
C  CALCULATE THE EQUIVALENT SPIN RATE OF THE SFF LINER
C  BASED ON THE CONSERVATION OF ANGULAR MOMENTUM
```

```
C
      READ(5,100)ISPIN
  100 FORMAT(I5)
      IF(ISPIN.NE.1)GO TO 500
      WRITE(6,200)
  200 FORMAT(1H ,//,15X,'LINER DATA',/)
      WRITE(6,205)
  205 FORMAT(1H ,8X,'TLS',13X,'HLS',12X,'RCS',10X,'AMASSL',5X,
     1 'SEGMENT',/)
      TAM=AIB*W
      READ(5,100)NLS
      TMASSL=0.0
      SUM1=0.0
      DO 105 I=1,NLS
      READ(5,110)TLS(I),HLS(I),RCS(I)
  110 FORMAT(3F10.5)
      AMASSL(I)=DEN*TLS(I)*HLS(I)*RCS(I)*2.*PI
      TMASSL=TMASSL+AMASSL(I)
      WRITE(6,210)TLS(I),HLS(I),RCS(I),AMASSL(I),I
  210 FORMAT(1H ,3(5X,F10.5),E12.5,I5)
      SUM1=SUM1+AMASSL(I)*RCS(I)**2.
  105 CONTINUE
      WL=TAM/SUM1
      RPML=WL*30./PI
      WRITE(6,215)TMASSL
  215 FORMAT(1H ,5X,'TOTAL MASS OF THE LINER = ',E15.6,/)
      WRITE(6,220)WL,RPML
  220 FORMAT(1H ,5X,'SFF IS DYNAMICALLY STABLE AT CHARGE SPIN ',
     1 'RATES GREATER THAN ',E12.6,3X,'(RAD/SEC)',E12.6,3X,'(RPM)')
      GO TO 500
   10 IF(CMAT.LT.0.0)GO TO 50
      WRITE(6,40)CMAT
      WRITE(6,55)SD
   55 FORMAT(1H ,5X,'SD =',F10.5,5X,'(NOT IN THE RANGE 0-2)')
      WRITE(6,60)
   60 FORMAT(1H ,5X,'BODY IS DYNAMICALLY UNSTABLE AT ANY SPINRATE')
      GO TO 500
   50 SGI=SD*(2.-SD)
      SG=1./SGI
      SGA=ABS(SG)
      W=(SGA*PI*RHO*TIB*ABS(CMAT)*DB**3./(2.*AIB**2.))**.5*VEL
      RPM=W*30./PI
      WRITE(6,25)CMAT
      WRITE(6,55)SD
      WRITE(6,65)SGI,SG
      WRITE(6,70)W,RPM
   70 FORMAT(1H ,5X,'BODY IS DYNAMICALLY STABLE AT SPIN RATES ',
     1 'LESS THAN ',E12.6,3X,'(RAD/SEC)',E12.6,3X,'(RPM)')
  500 RETURN
      END
C
C************************************************************
C************************************************************
C
```

```
      SUBROUTINE SPLINE ( N , X , Y , B , C , D )
C
C  GENERATES CUBIC SPLINE COEFFICIENTS
C
      REAL X(101) , Y(101) , B(101) , C(101) , D(101)
      NM1 = N - 1
      IF(N-2)60,50,1
    1 D(1) = X(2) - X(1)
      C(2) = (Y(2) - Y(1))/D(1)
      DO 10 I=2,NM1
           D(I) = X(I+1) - X(I)
           B(I) = 2.*(D(I-1) + D(I))
           C(I+1) = (Y(I+1) - Y(I))/D(I)
           C(I) = C(I+1) - C(I)
   10 CONTINUE
      B(1) = -D(1)
      B(N) = -D(N-1)
      C(1) = 0.0
      C(N) = 0.0
      IF(N-3)11,15,11
   11 C(1) = C(3)/(X(4)-X(2)) - C(2)/(X(3)-X(1))
      C(N) = C(N-1)/(X(N)-X(N-2)) - C(N-2)/(X(N-1)-X(N-3))
      C(1) = C(1)*D(1)*D(1)/(X(4)-X(1))
      C(N) = -C(N)*D(N-1)*D(N-1)/(X(N)-X(N-3))
   15 DO 20 I=2,N
           T = D(I-1)/B(I-1)
           B(I) = B(I) - T*D(I-1)
           C(I) = C(I) -T*C(I-1)
   20 CONTINUE
      C(N) = C(N)/B(N)
      DO 30 IB = 1,NM1
           I = N - IB
           C(I) = (C(I) - D(I)*C(I+1))/B(I)
   30 CONTINUE
      B(N) = (Y(N) - Y(NM1))/D(NM1) + D(NM1)*(C(NM1) + 2.*C(N))
      DO 40 I = 1,NM1
           B(I) = (Y(I+1) - Y(I))/D(I) - D(I)*(C(I+1) + 2.*C(I))
           D(I) = (C(I+1) - C(I))/D(I)
           C(I) = 3.*C(I)
   40 CONTINUE
      C(N) = 3.*C(N)
      D(N) = D(N-1)
      RETURN
   50 B(1) = (Y(2)-Y(1))/(X(2)-X(1))
      C(1) = 0.0
      D(1) = 0.0
      B(2) = B(1)
      C(2) = 0.0
      D(2) = 0.0
   60 RETURN
      END
C
C***********************************************************
C
```

```
      SUBROUTINE SEVAL(X0,Y0,D1Y0,D2Y0,D3Y0, X,Y,B,C,D,N)
C
C  EVALUATES CUBIC SPLINE FOR A GIVEN ABSCISSA
C
      REAL X(100) , Y(100) , B(100) , C(100) , D(100)
      DATA I/1/
      IF(I-N)2,1,1
    1 I = 1
    2 IF(X0-X(I)) 10,3,3
    3 IF(X0-X(I+1)) 30,30,10
   10 I = 1
      J = N + 1
   20 K = (I+J)/2
      IF(X0-X(K)) 21,22,22
   21 J = K
      GO TO 23
   22 I = K
   23 IF(J - (I+1))30,30,20
   30 DX = X0 - X(I)
      Y0 = Y(I) + DX*(B(I) + DX*(C(I) + DX*D(I)))
      D1Y0 = B(I) + DX*(2.*C(I) + 3.*D(I)*DX)
      D2Y0 = 2.*C(I) + 6.*D(I)*DX
      D3Y0 = 6.*D(I)
      RETURN
      END
```

SFFSTAB INPUT

TITLE CARD (13A6, 2A1)

BODY MATERIAL DENSITY (F10.5)

DEN	
10	

SEGMENT CARD (2I5)

ITYPE	NSEG	
5	10	

ITYPE = 0 - spherical segments and truncated cones are used
1 - only truncated cones are used
NSEG = number of segments

INDIVIDUAL SEGMENT CARDS - AS REQUIRED

SPHERICAL SEGMENT CARD (I5, 5X, 3F10.5) - AS REQUIRED

ISEG		R2	R1	H	
5	10	20	30	40	

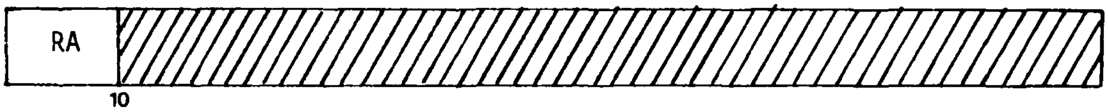
ISEG = segment number
R2 = outer radius
R1 = inner radius
H = segment height

TRUNCATED CONE SEGMENT CARD (I5, 5X, 5F10.5) - AS REQUIRED

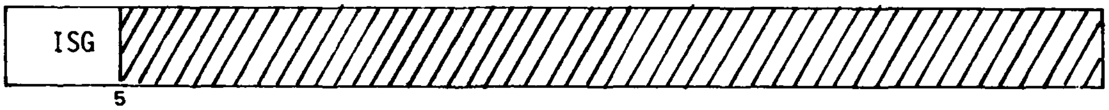
ISEG		RR2	RR1	R2	R1	H	
5	10	20	30	40	50	60	

ISEG = segment number
RR2 = outer radius at large end
RR1 = inner radius at large end
R2 = outer radius at small end
R1 = inner radius at small end
H = segment height

REFERENCE AXIS (F10.5) RA = 0.0 if C of G is to be used

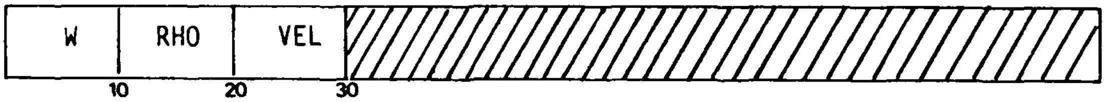


GYROSCOPIC STABILITY CARD (I5)



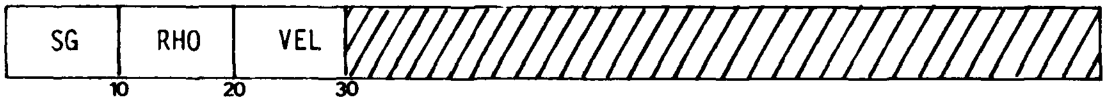
ISG = 0 - calculate SG
= 1 - calculate W

CARD FOR ISG = 0 (3F10.5) - AS REQUIRED



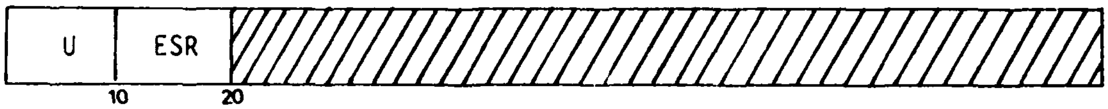
W = spin rate (RAD/SEC)
RHO = air density (lb sec^2/in^4)
VEL = body velocity (in/sec)

CARD FOR ISG = 1 (3F10.5) - AS REQUIRED



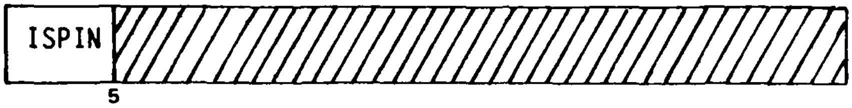
SG = gyroscopic stability factor

DRAG PARAMETERS CARD (2E10.5)



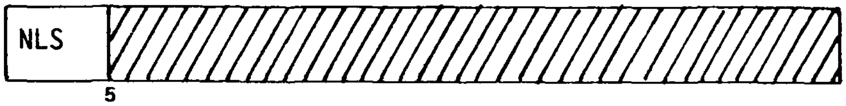
U = absolute viscosity (lb sec/in^2)
ESR = equivalent sand roughness (in)

(I5)



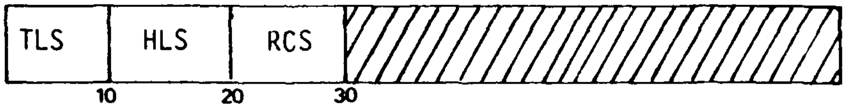
ISPIN = 1 → calculates charge spin rate

(I5)



NLS = number of liner segments

(3F10.5)



ONLY FOR ISPIN = 1

o
o
o

Repeat for each segment

TLS = thickness of segment
HLS = height of segment
RCS = radius of centroid of crossectional area of liner segment

SAMPLE PROBLEM INPUT

```
BASELINE DESIGN SHOT #01
   .000837
    0    5
    1          .3564      0.0      .2152
    2          .4048      0.0      .3193      0.0      .2024
    3          .4576      0.0      .4048      0.0      .3107
    4          .4704      0.0      .4576      0.0     1.1717
    5          .5488      0.0      .4704      0.0      .6942
        0.0
    1
        1.0.000000115    92262.
2.5932E-09   .16E-03
    1
   20
       .121          .1       .05
       .122          .1       .15
       .123          .1       .25
       .124          .1       .35
       .125          .1       .45
       .126          .1       .55
       .127          .1       .65
       .128          .1       .75
       .129          .1       .85
       .129          .1       .95
       .129          .1      1.05
       .130          .1      1.15
       .130          .1      1.25
       .129          .1      1.35
       .129          .1      1.45
       .128          .1      1.55
       .127          .1      1.65
       .125          .1      1.75
       .124          .1      1.85
       .121          .1      1.95
```

SAMPLE PROBLEM OUTPUT

```
BASELINE DESIGN SHOT #01

1        ***** GYROSCOPIC STABILITY DATA *****

DENSITY =      .00083700     ITYPE =    0     NUMBER OF SEGMENTS =    5
  ISEG          RR2            RR1             R2            R1            H

    1                                        .35640        .00000        .21520
    2          .40480         .00000         .31930        .00000        .20240
    3          .45760         .00000         .40480        .00000        .31070
    4          .47040         .00000         .45760        .00000       1.17170
    5          .54880         .00000         .47040        .00000        .69420
REFERENCE AXIS =     .00000      ISG =    1
SG =   1.00000      RHO =     .000000114999999      VELOCITY =     92262.00000

 PROPERTIES FOR SEGMENT NUMBER     1
     HOLLOW SPHERICAL SEGMENT
OUTER RADIUS =       .35640     INNER RADIUS =      .00000     HEIGHT =       .21520
DENSITY =        .00083700      VOLUME =         .03846823     MASS =        .00003220
DISTANCE FROM REFERENCE AXIS TO CENTROID =        .22600125
DISTANCE FROM BASE OF SEGMENT TO CENTROID =        .08480125
AXIAL MOMENT OF INERTIA =          .00000135
TRANSVERSE MOMENT OF INERTIA =          .00000073
NOSE BLUNTNESS =    .60382     CNAP =     .84218     CMAP =    -.45965

 PROPERTIES FOR SEGMENT NUMBER     2
     HOLLOW TRUNCATED CONE
OUTER RADIUS AT LARGE END =      .40480      INNER RADIUS AT LARGE END =      .00000
OUTER RADIUS AT SMALL END =      .31930      INNER RADIUS AT SMALL END =      .00000
HEIGHT =      .20240
DENSITY =        .00083700      VOLUME =        .08373579     MASS =        .00007009
DISTANCE FROM CONE BASE TO CENTROID =        .09327055
AXIAL MOMENT OF INERTIA =          .00000470
TRANSVERSE MOMENT OF INERTIA =          .00000259
THETA =   22.90069      A/D =     .78878     CNAP =     .62997     CMAP =    -.21029

 PROPERTIES FOR SEGMENT NUMBER     3
     HOLLOW TRUNCATED CONE
OUTER RADIUS AT LARGE END =      .45760      INNER RADIUS AT LARGE END =      .00000
OUTER RADIUS AT SMALL END =      .40480      INNER RADIUS AT SMALL END =      .00000
HEIGHT =      .31070
DENSITY =        .00083700      VOLUME =        .18171506     MASS =        .00015210
DISTANCE FROM CONE BASE TO CENTROID =        .14901710
AXIAL MOMENT OF INERTIA =          .00001423
TRANSVERSE MOMENT OF INERTIA =          .00000833
THETA =    9.64464      A/D =     .88462     CNAP =     .41093     CMAP =    -.11247
```

PROPERTIES FOR SEGMENT NUMBER 4
HOLLOW TRUNCATED CONE
OUTER RADIUS AT LARGE END = .47040 INNER RADIUS AT LARGE END = .00000
OUTER RADIUS AT SMALL END = .45760 INNER RADIUS AT SMALL END = .00000
HEIGHT = 1.17170
DENSITY = .00083700 VOLUME = .79255570 MASS = .00066337
DISTANCE FROM CONE BASE TO CENTROID = .58046321
AXIAL MOMENT OF INERTIA = .00007143
TRANSVERSE MOMENT OF INERTIA = .00011159
THETA = .62589 OUT OF THETA RANGE
THETA = .62589 A/D = .97279 CNAP = .09950 CMAP = .00000

PROPERTIES FOR SEGMENT NUMBER 5
HOLLOW TRUNCATED CONE
OUTER RADIUS AT LARGE END = .54880 INNER RADIUS AT LARGE END = .00000
OUTER RADIUS AT SMALL END = .47040 INNER RADIUS AT SMALL END = .00000
HEIGHT = .69420
DENSITY = .00083700 VOLUME = .56747804 MASS = .00047498
DISTANCE FROM CONE BASE TO CENTROID = .32933503
AXIAL MOMENT OF INERTIA = .00006228
TRANSVERSE MOMENT OF INERTIA = .00005010
THETA = 6.44344 A/D = .85714 CNAP = .51445 CMAP = -.20205

ISEG	DBCS	DCBCS	DB
1	2.46380	1.35312	.65447
2	2.26987	1.15919	.80960
3	2.01492	.90424	.91520
4	1.27466	.16398	.94080
5	.32934	.78135	1.09760

TOTAL VOLUME OF BODY = 1.66395
TOTAL MASS OF BODY = .00139
CENTER OF GRAVITY OF BODY (RELATIVE TO BASE) = 1.11068
AXIAL MOMENT OF INERTIA OF BODY = .00015
TRANSVERSE MOMENT OF INERTIA OF BODY = .00076
CNA FOR THE BODY = 1.51543

ISEG	DBFS	DBFSRA	CMA	CMAL
1	2.59420	1.48352	1.44936	4.40782
2	2.37900	1.26832	.77662	3.10648
3	2.17660	1.06592	.36613	1.07849
4	1.86590	.75522	.07988	.06414
5	.69420	-.41648	-.39725	-.62809

```
TOTAL CNA FOR THE BODY =    1.51543
TOTAL CMA FOR THE BODY (BASED ON AREA AND BASE DIAMETER =     .48424
TOTAL CMA FOR THE BODY (BASED ON AREA AND BODY LENGTH =    .20488
LENGTH OF THE BODY =   2.59420
CENTER OF PRESSURE AS A FRACTION OF BODY LENGTH =    .43666
SPIN RATE (RAD/SEC) =      5612.35498     SPIN RATE (RPM) =     53594.04440
OUT OF THETA RANGE
OUT OF THETA RANGE
     ***** DYNAMIC STABILITY DATA *****
EQUIVALENT SAND ROUGHNESS = .160000E-03     ADMISSIBLE ROUGHNESS = .162137E+05
REYNOLDS NUMBER = .106142E+08     ABSOLUTE VISCOSITY = .259320E-08
CUTOFF REYNOLDS NUMBER = .982166E+06
BODY MAXIMUM FRONTAL AREA =     .94619     BODY WETTED AREA =   7.48865
DIMENSIONLESS AXIAL RADIUS OF GYRATION =     .30295     DIMENSIONLESS TRANSVERSE RADIUS OF GYRATION =     .67242

PROPERTIES FOR SEGMENT NUMBER      1
CDP =    1.15696     CNQP =     .91817
CMQP =    -.50000     CMQ =  -4.98937

PROPERTIES FOR SEGMENT NUMBER      2
CDP =     .11442     CNQP =     .41000
CMQP =    -.14031     CMQ =  -1.93131

PROPERTIES FOR SEGMENT NUMBER      3
CDP =     .01221     CNQP =     .21421
CMQP =    -.06286     CMQ =   -.66624

PROPERTIES FOR SEGMENT NUMBER      4
CDP =     .00001     CNQP =     .00000
CMQP =     .00000     CMQ =   -.12824

PROPERTIES FOR SEGMENT NUMBER      5
CDP =     .00668     CNQP =     .39492
CMQP =    -.18459     CMQ =   -.63591
```

INCOMPRESSIBLE FLAT PLATE SKIN FRICTION COEFFICIENT (CF) = .00447
COMPRESSIBLE/INCOMPRESSIBLE SKIN FRICTION COEFFICIENT (CFCCF) = .29972
BODY SKIN FRICTION DRAG COEFFICIENT (CDF) = .01080
BODY BASE DRAG COEFFICIENT (CDB) = .02795
BODY ZERO LIFT DRAG COEFFICIENT (CDO) = .52754
BODY PITCHING DERIVATIVE (CMQT) = -2.22958
DERIVATIVE OF THE MAGNUS MOMENT COEFFICIENT (CMPA)= .01113
BODY ACCELERATION DERIVATIVE (CMPA) = .00000
DYNAMIC STABILITY FACTOR (SD) = .41145
CMA = .48424 (POSITIVE)
SD = .41145 (IN THE RANGE 0-2)
SGI = .65361 SG = 1.52996 (VALUES ON DYNAMIC STABLE/UNSTABLE CURVE)
BODY IS DYNAMICALLY STABLE AT SPIN RATES GREATER THAN .694200E+04 (RAD/SEC) .662912E+05 (RPM)

LINER DATA

TLS	HLS	RCS	AMASSL	SEGMENT
.12100	.10000	.05000	.31817E-05	1
.12200	.10000	.15000	.96240E-05	2
.12300	.10000	.25000	.16172E-04	3
.12400	.10000	.35000	.22824E-04	4
.12500	.10000	.45000	.29582E-04	5
.12600	.10000	.55000	.36445E-04	6
.12700	.10000	.65000	.43413E-04	7
.12800	.10000	.75000	.50487E-04	8
.12900	.10000	.85000	.57665E-04	9
.12900	.10000	.95000	.64449E-04	10
.12900	.10000	1.05000	.71234E-04	11
.13000	.10000	1.15000	.78622E-04	12
.13000	.10000	1.25000	.85459E-04	13
.12900	.10000	1.35000	.91586E-04	14
.12900	.10000	1.45000	.98370E-04	15
.12800	.10000	1.55000	.10434E-03	16
.12700	.10000	1.65000	.11020E-03	17
.12500	.10000	1.75000	.11504E-03	18
.12400	.10000	1.85000	.12064E-03	19
.12100	.10000	1.95000	.12409E-03	20

TOTAL MASS OF THE LINER = .133343E-02

SFF IS DYNAMICALLY STABLE AT CHARGE SPIN RATES GREATER THAN .404143E+03 (RAD/SEC) .385928E+04 (RPM)

UNCLASSIFIED

This Sheet Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1 ORIGINATING ACTIVITY Defence Research Establishment Suffield	2a. DOCUMENT SECURITY CLASSIFICATION Unclassified 2b GROUP

3 DOCUMENT TITLE

SFFSTAB: A COMPUTER PROGRAM TO CALCULATE THE AERODYNAMIC STABILITY OF A SELF-FORGING FRAGMENT

4 DESCRIPTIVE NOTES (Type of report and inclusive dates) SUFFIELD MEMORANDUM NO. 1194

5. AUTHOR(S) (Last name, first name, middle initial)

Weickert, C.A.

6. DOCUMENT DATE March 1987	7a. TOTAL NO. OF PAGES 102	7b. NO. OF REFS 6

8a. PROJECT OR GRANT NO. 231SB	9a. ORIGINATOR'S DOCUMENT NUMBER(S) SM 1194
8b CONTRACT NO.	9b. OTHER DOCUMENT NO.(S) (Any other numbers that may be assigned this document)

10. DISTRIBUTION STATEMENT

UNLIMITED

11 SUPPLEMENTARY NOTES	12. SPONSORING ACTIVITY

13. ABSTRACT

An aerodynamic stability computer program (SFFSTAB) has been developed for calculating the spin rate required for stabilization of a self-forging fragment. An aerodynamic stability criterion which combined gyroscopic and dynamic stability was used together with a technique for calculating aerodynamic coefficients. SFFSTAB is a useful tool for conducting aerodynamic stability parameter studies for different fragment shapes. Complete documentation of the computer program including sample problem, flowchart and FORTRAN listing is provided.

UNCLASSIFIED

This Sheet Security Classification

KEY WORDS

SELF-FORGING FRAGMENT, SPIN, SPIN STABILIZATION, AERODYNAMIC STABILITY, EXPLOSIVES, FLASH X-RAY

INSTRUCTIONS

1. ORIGINATING ACTIVITY Enter the name and address of the organization issuing the document.

2a DOCUMENT SECURITY CLASSIFICATION Enter the overall security classification of the document including special warning terms whenever applicable.

2b GROUP Enter security reclassification group number. The three groups are defined in Appendix 'M' of the DRB Security Regulations.

3 DOCUMENT TITLE Enter the complete document title in all capital letters. Titles in all cases should be unclassified. If a sufficiently descriptive title cannot be selected without classification, show title classification with the usual one-capital-letter abbreviation in parentheses immediately following the title.

4 DESCRIPTIVE NOTES Enter the category of document, e.g. technical report, technical note or technical letter. If appropriate, enter the type of document, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.

5 AUTHOR(S) Enter the name(s) of author(s) as shown on or in the document. Enter last name, first name, middle initial. If military, show rank. The name of the principal author is an absolute minimum requirement.

6 DOCUMENT DATE Enter the date (month, year) of Establishment approval for publication of the document.

7a TOTAL NUMBER OF PAGES The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b NUMBER OF REFERENCES Enter the total number of references cited in the document.

8a PROJECT OR GRANT NUMBER If appropriate, enter the applicable research and development project or grant number under which the document was written.

8b CONTRACT NUMBER If appropriate, enter the applicable number under which the document was written.

9a ORIGINATOR'S DOCUMENT NUMBER(S) Enter the official document number by which the document will be identified and controlled by the originating activity. This number must be unique to this document.

9b. OTHER DOCUMENT NUMBER(S) If the document has been assigned any other document numbers (either by the originator or by the sponsor), also enter this number(s).

10. DISTRIBUTION STATEMENT Enter any limitations on further dissemination of the document, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this document from their defence documentation center."

(2) "Announcement and dissemination of this document is not authorized without prior approval from originating activity."

11. SUPPLEMENTARY NOTES Use for additional explanatory notes.

12. SPONSORING ACTIVITY Enter the name of the departmental project office or laboratory sponsoring the research and development. Include address.

13 ABSTRACT Enter an abstract giving a brief and factual summary of the document, even though it may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall end with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (TS), (S), (C), (R), or (U).

The length of the abstract should be limited to 20 single-spaced standard typewritten lines 7½ inches long.

14 KEY WORDS Key words are technically meaningful terms or short phrases that characterize a document and could be helpful in cataloging the document. Key words should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context.

END

6-87

DTIC